

**PHENYLALANINE AMMONIA LYASE POLYPEPTIDE
AND POLYNUCLEOTIDE SEQUENCES AND METHODS OF OBTAINING
AND USING SAME**

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part application of U.S. patent application Serial No. 09/624,693, filed July 24, 2000, now allowed, and is a continuation-in-part application of PCT International Application PCT/US01/23270, having an international filing date of July 24, 2001.

TECHNICAL FIELD OF THE INVENTION

The present invention relates *inter alia* to a *Rhodotorula* phenylalanine lyase polypeptide, to polynucleotides encoding the polypeptide, and to methods of obtaining and using these products.

BACKGROUND OF THE INVENTION

Phenylalanine ammonia lyase (PAL; EC 4.3.1.5.) is an enzyme that is found in several plants, yeast, and *Streptomyces*. PAL catalyzes the nonoxidative deamination of L-phenylalanine to *trans*-cinnamic acid. The enzyme has a potential role in the treatment and diagnosis of phenylketonuria (Ambrus et al., *Science*, 201, 837-839 (1978)) and cancer, and is commercially useful for the manufacture of L-phenylalanine from ammonia and *t*-cinnamate.

Many references describe PAL-producing yeast strains that are useful in fermentation cultures for producing phenylalanine. *Rhodotorula glutinis* can be employed to obtain PAL activity in the presence of inducer, but the activity reaches a maximum after about six hours of induction and then diminishes thereafter. PAL similarly is rapidly degraded in the absence of the inducer during fermentation and has a half-life of approximately 2-5 hours during fermentations of most *Rhodotorula rubra* strains.

U.S. Patent 4,598,047 describes mutant strains of *Rhodotorula rubra* (GX 5902, GX 5903, GX 5904 specifically) that are useful for PAL production. *Rhodotorula graminis* wild-type strain KGX 39 (also known as GX 5007) is a soil

isolate that similarly has PAL activity (Durham et al., *J. Bact.*, 160, 771-777 (1984)). KGX 39 has several advantages over other production strains of *Rhodotorula rubra*. It grows 15-20% faster and requires less yeast extract, has no L-methionine requirement during induction, and its PAL half-life during fermentation is about 8 to 9
5 hours. *R. graminis* KGX 39, however, is undesirable as a production strain due to low PAL titers obtained during fermentation.

An over-producing PAL mutant also has been obtained by mutagenesis of strain KGX 39, as described in U.S. Patent 4,757,015. This mutagenized strain (deposited as ATCC 20804) has high PAL specific activity and titer, high PAL
10 specific productivity, high stability, and lower fermentation times to maximum PAL concentration than any of the previously-available PAL-producing yeast strains.

The use of yeast-derived PAL to produce a variety of optically-active unnatural amino acids having phenylalanine-like structures as chiral synthons for synthesis recently has been described (see, U.S. Patent 5,981,239, incorporated by
15 reference in its entirety herein). According to this reference, the stereospecific introduction of ammonia is accomplished with use of microorganism cells (*i.e.*, cells of the yeast strain *Rhodotorula graminis* ATCC 20804) as the biocatalyst for the stereospecific conversion. Phenylalanine ammonia lyase from *R. graminis* ATCC 20804 was found to demonstrate broad substrate specificity for introduction of a
20 molecule of ammonia stereoselectively onto the double bond of a 3-substituted acrylic acid. This newly discovered activity of *R. graminis* PAL should prove useful commercially.

In particular, phenylalanine and its derivatives also have been used as essential building blocks in the construction of various types of biologically active molecules.
25 For instance, protease inhibitors employed in the treatment of human immunodeficiency virus and human cytomegalovirus infections contain a phenylalanine-like architecture as their pharmacophores. Presently there is a need for a general process of preparing a variety of optically active unnatural amino acids (*i.e.*, amino acids that are not found in nature) having phenylalanine-like structures as
30 chiral synthons for synthesis of these drug candidates. Based on the broad substrate specificity of *R. graminis*, it would be useful to obtain the polypeptide and nucleic

acid sequences of its PAL, e.g., amongst other things, for optimization of its enzymatic activities in these synthesis reactions.

Accordingly, while polynucleotides encoding phenylalanine ammonia lyase have been isolated from the yeasts *Rhodosporidium toruloides* (PCT WO 88/02824) and *Rhodotorula rubra* (Filpula et al., *Nucleic Acids Research*, 16, 11381 (1988), it would be useful to obtain the polynucleotide sequence of still other species. There is a need for strains that can be employed for the production of phenylalanine, phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures. The present invention thus is directed, amongst other things, to methods, vectors, sequences, and compositions to meet that need. These and other objects and advantages of the present invention, as well as additional inventive features, will be apparent from the description of the invention provided herein. The description and examples are provided to enhance the understanding of the invention, but are not intended to in any way limit the scope of the invention.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a *Rhodotorula* phenylalanine lyase polypeptide, polynucleotides encoding the polypeptide, and methods of obtaining and using these products.

BRIEF DESCRIPTION OF THE FIGURES

Figures 1A-1B are the alignment of PAL polypeptide sequences of *R. graminis* strain ATCC 20804 (SEQ ID NO:13), *R. toruloides* (SEQ ID NO:19), and *R. mucilaginosa* (SEQ ID NO:17), and the consensus of these sequences (SEQ ID NO:21), as described in Example 3. Gaps in the sequence are denoted with a hyphen, "X" (i.e., "Xaa" in the three-letter code) means there is no consensus between the sequences at that amino acid residue.

Figures 2A-2F are the alignment of PAL polynucleotide sequences (cDNA sequences) of *R. graminis* (SEQ ID NO:12, residues 37-2419), *R. toruloides* (SEQ ID NO:18), and *R. rubra/mucilaginosa* (SEQ ID NO:16, residues 646-2787), and the consensus of these sequences (SEQ ID NO:20). Gaps in this figure are denoted with a

hyphen, "N" means there is no consensus between the sequences at that nucleic acid residue.

Figure 3 is the PAL genomic DNA sequence of ATCC 20804 (SEQ ID NO:28) with introns underlined.

5 **Figure 4** is the PAL genomic DNA sequence of KGX 39 (SEQ ID NO:28) with introns underlined.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 The present invention provides, amongst other things, novel purified and isolated yeast PAL sequences, particularly those of the yeast *Rhodotorula*, and especially those of the yeast *Rhodotorula graminis*.

Of course, the sequences of the invention optionally can be present either in their polypeptide/protein form (*e.g.*, in the "polypeptide sequence"), or, in the form of their encoding nucleic acids (*e.g.*, either as purified nucleic acid species, and/or in 15 certain of the vectors). As used herein, lower case "pal" refers to a nucleic acid sequence whereas upper case "PAL" refers to an amino acid sequence.

PAL Polypeptides

The present invention provides, *inter alia*, novel purified and isolated yeast PAL polypeptides.

20 The conventional abbreviations for amino acids comprising proteins and peptides are used herein as generally accepted in the peptide art and as recommended by the IUPAC-IUB Commission on Biochemical Nomenclature (See, *European J. Biochem.*, 138, 9-37 (1984)). Similarly, protein and peptide sequences are written according to the standard convention wherein the N-terminal amino acid is on the left and the C-terminal amino acid is on the right (with corresponding nucleic acid 25 sequences being written in a 5' to 3' direction). The term "peptide" as used herein refers to any length molecular chain of amino acids linked by peptide bonds. As used herein, "protein" refers to the full length (*i.e.*, complete) protein. The term "peptide" encompasses the term "polypeptide", which, as used herein, refers more specifically to a linear polymer of more than 3 amino acids, and which can either be a complete 30 protein (*i.e.*, having both amino and carboxy terminuses), or an incomplete protein

(i.e., lacking either an amino or carboxy terminus). The polypeptides of the invention desirably can be modified such as is known in the art.

The proteins of the present invention preferably comprise an amino end and a carboxyl end. However, polypeptides having a modified amino- and/or carboxy-terminus are desirable since proteins and peptides with modified termini are expected to have longer in vivo half-lives since endopeptidases have reduced activity with respect to proteins and peptides with modified termini. The polypeptides can comprise D- or L- peptides, or a mixture of the D- and L-amino acid forms. Polypeptides (particularly proteins) comprising L-amino acids are preferred. However, the D-form of the amino acids are also desirable since proteins and polypeptides comprising D-amino acids are expected to have a greater retention of their biological activity in vivo given that the D-amino acids are not recognized by naturally occurring proteases.

The invention thus also provides purified and isolated yeast PAL polypeptides. An exemplary PAL polypeptide has an amino acid sequence defined in SEQ ID NO:13. PAL polypeptides of the invention preferably are isolated from natural cell sources, or chemically synthesized, or desirably are produced by recombinant procedures involving host cells of the invention. PAL polypeptides of the invention preferably are full-length polypeptides, or variant polypeptides such as fragments, truncates, deletion mutants, and other variants thereof that retain specific PAL biological activity. As used herein, "biologically active" refers to a PAL polypeptide having at least one of the structural, regulatory or biochemical functions of the naturally occurring PAL protein. Specifically, a PAL protein of the present invention has the ability to manufacture phenylalanine, phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures, when provided with the appropriate substrates.

The polypeptide and polypeptide fragments of the present invention preferably are prepared by methods known in the art. Such methods include, but are not limited to, isolating these products directly from cells, isolating or synthesizing DNA encoding these products and using the DNA to produce recombinant products,

synthesizing the products chemically from individual amino acids, and production of fragments by chemical cleavage of existing products.

5 The PAL polypeptides can be isolated from a biological sample, such as a solubilized cell fraction, by any standard method known in the art. Some suitable methods include precipitation and liquid chromatographic protocols such as ion exchange, hydrophobic interaction, and gel filtration, as well as immunoaffinity purification. See, for example, Deutscher (Ed.), *Methods Enzymol (Guide to Protein Chemistry, Section VII)*, 182:309 (1990) and Scopes, *Protein Purification*, Springer-Verlag, New York (1987). Also, purified material desirably is obtained by separating
10 the protein on preparative SDS-PAGE gels, slicing out the band of interest, and electroeluting the protein from the polyacrylamide matrix by methods known in the art. The detergent SDS is removed from the protein by known methods, such as by dialysis or the use of a suitable column, such as the Extracti-Gel column from Pierce.

The PAL polypeptides of the invention also can be chemically synthesized,
15 wholly or in part, by methods known in the art. In particular, chemical synthesis may prove useful for production of only portions of a PAL polypeptide (*i.e.*, PAL fragments), particularly those fragments less than about 200 amino acids in length. Suitable methods for synthesizing the protein are described by Stuart and Young, *Solid Phase Peptide Synthesis*, 2d ed., Pierce Chemical Co. (1984), and Bodanszky, *Principles of Peptide Synthesis*, (Springer-Verlag, Heidelberg: 1984)). For example,
20 peptides can be synthesized by solid phase techniques, cleaved from the resin, and purified by preparative high performance liquid chromatography (HPLC). See, *e.g.*, Roberge *et al.*, *Science*, 269:202-204 (1995). In particular, the peptides can be synthesized using the procedure of solid-phase synthesis (see, *e.g.*, Merrifield, *J. Am. Chem. Soc.*, 85, 2149-54 (1963); Barany *et al.*, *Int. J. Peptide Protein Res.*, 30, 705-739 (1987); and U.S. Patent 5,424,398), and modifications thereof. If desired, this
25 can be done using an automated peptide synthesizer (*e.g.*, Perkin Elmer ABI 431A Peptide Synthesizer, or other appropriate synthesizer) according to the instructions of the manufacturer. Removal of the t-butyloxycarbonyl (t-BOC) or 9-fluorenylmethyloxycarbonyl (Fmoc) amino acid blocking groups and separation of
30 the peptide from the resin can be accomplished by, for example, acid treatment at

reduced temperature. The peptide-containing mixture can then be extracted, for instance, with dimethyl ether, to remove non-peptide organic compounds, and the synthesized peptides can be extracted from the resin powder (*e.g.*, with about 25% w/v acetic acid). Following the synthesis of the peptide, further purification (*e.g.*, using high performance liquid chromatography (HPLC)) optionally can be done in order to eliminate any incomplete peptides or free amino acids. Amino acid analysis and/or sequencing (*e.g.*, the Edman degradation procedure) can be performed on the synthesized polypeptides to validate the composition of the synthetic peptides.

As described in greater detail below (section on polypeptide expression systems), recombinant PAL protein also may be produced in and isolated from a host cell transformed with an expression vector containing a *pal* nucleotide sequence and grown in culture. A PAL-encoding polynucleotide of the invention can be introduced by any means into either a prokaryotic or eukaryotic cell in a manner that permits directed expression of a PAL polypeptide. In such methods, the host cells are grown in a suitable culture medium and the desired polypeptide products are isolated from the cells or from the medium in which the cells are grown. Isolation of the polypeptides can be accomplished by any appropriate means such as is known in the art.

The invention includes polypeptides comprising amino acid sequences that are substantially homologous to the sequences of PAL polypeptides described herein. For example, the invention includes polypeptides whose corresponding amino acid sequences have at least 80%, preferably at least 90%, more preferably at least 91%, 92%, 93%, 94%, or 95% identity, and still more preferably at least 98% identity (or, also desirably, similarity) with the polypeptide sequence defined in SEQ ID NO:13.

Percent sequence "identity" with respect to a preferred polypeptide of the invention can be defined as the percentage of amino acid residues in a candidate sequence that are identical to amino acid residues in the reference PAL sequence after aligning the sequences and introducing gaps, if necessary, to achieve maximum percent sequence identity, and not considering any conservative substitutions as part of the sequence identity. Percent sequence "similarity" with respect to a preferred polypeptide of the invention can be defined as the percentage of amino acid residues

in a candidate sequence that are identical to amino acid residues in the reference PAL sequence after aligning the sequences and introducing gaps, if necessary, to achieve maximum percent sequence identity, and also considering any conservative substitutions as part of the sequence identity.

5 Sequence alignment of polypeptides for purposes of sequence comparison can be done using a variety of multiple alignment servers, most of which are presently available on the Internet, *e.g.*, Clustal W, MAP, PIMA, Block Maker, MSA, MEME, and Match-Box. Preferably Clustal W (Higgins et al., *Gene*, 73, 237-244 (1988); Higgins et al., *Meth. Enzymol.*, 266, 383-402 (1996)) is employed for sequence
10 alignment of polypeptides (and also, polynucleotides). Similarly, the program BLASTP compares an amino acid query sequence against a protein database, and TBLASTN compares a protein query sequence against a nucleotide sequence database dynamically translated in all six reading frames (both strands), and can be employed in the invention.

15 Determinations of whether two amino acid sequences are substantially homologous (*i.e.*, similar or identical) also can be based on FASTA searches in accordance with Pearson et al., *Proc. Natl. Acad. Sci. USA*, 85:2444-2448 (1988). Alternatively (but less preferably), percent homology is calculated as the percentage of amino acid residues in the smaller of the two sequences that align with identical
20 amino acid residues in the sequence being compared, when four gaps in a length of 100 amino acids may be introduced to maximize alignment. See Dayhoff, in *Atlas of Protein Sequence and Structure*, Vol. 5, p. 124, National Biochemical Research Foundation, Washington, D.C. (1972).

In particular, preferred methods to determine sequence similarities are
25 designed to give the largest match between the compared sequences. Methods to determine identity and similarity are codified in publicly available computer programs (*e.g.*, such as those previously described). Preferred computer program methods to determine identity and similarity between two sequences include, but are not limited to, the GCG program package, including GAP (Devereux *et al.*, *Nucleic Acids
30 Research* 12(1):387 (1984); Genetics Computer Group, University of Wisconsin, Madison, WI), BLASTP, BLASTN, and FASTA (Altschul *et al.*, *J. Molec. Biol.*

215:403-410 (1990)). The BLASTX program is publicly available from the National Center for Biotechnology Information (NCBI) and other sources (Altschul *et al.*, *BLAST Manual*, NCB NLM NIH Bethesda, MD 20894; Altschul *et al.*, *J. Mol. Biol.*, 215:403-410 (1990)). The well-known Smith-Waterman algorithm also may be used
5 to determine relative identity.

By way of example, using the computer algorithm GAP, two polypeptides for which the percent sequence identity is to be determined are aligned for optimal matching of their respective amino acids (the "matched span", as determined by the algorithm). A gap opening penalty (which is calculated as 3 X the average diagonal;
10 the "average diagonal" is the average of the diagonal of the comparison matrix being used; the "diagonal" is the score or number assigned to each perfect amino acid match by the particular comparison matrix) and a gap extension penalty (which is usually 1/10 of the gap opening penalty), as well as a comparison matrix such as PAM 250 or BLOSUM 62 are used in conjunction with the algorithm. A standard comparison
15 matrix (see Dayhoff *et al.*, in: *Atlas of Protein Sequence and Structure*, vol. 5, supp.3 (1978) for the PAM250 comparison matrix; see Henikoff *et al.*, *Proc. Natl. Acad. Sci USA*, 89:10915-10919 (1992) for the BLOSUM 62 comparison matrix) is also used by the algorithm.

Preferred parameters for polypeptide sequence comparison include the
20 following:

Algorithm: Needleman and Wunsch, *J. Mol. Biol.* (1970) 48:443-453,
Comparison matrix: BLOSUM 62 from Henikoff and Henikoff, *Proc. Natl. Acad. Sci. USA* 89:10915-10919 (1992).

Gap Penalty: 12
25 Gap Length Penalty: 4
Threshold of Similarity: 0

The aforementioned parameters are the default parameters for polypeptide comparisons (along with no penalty for end gaps) using the GAP algorithm.

Preferred parameters for nucleic acid sequence comparison include the
30 following:

Algorithm: Needleman and Wunsch, *J. Mol Biol.* 48:443-453 (1970)

Comparison matrix: matches = +10, mismatch = 0

Gap Penalty: 50

Gap Length Penalty: 3

5 The aforementioned parameters are the default parameters for nucleic acid molecule comparisons.

Other exemplary algorithms, gap opening penalties, gap extension penalties, comparison matrices, thresholds of similarity, and the like may be used by those of skill in the art, including use of those parameters set forth in the Program Manual, Wisconsin Package, Version 9, September, 1997. The particular choices to be made
10 will depend on the specific comparison to be made, such as DNA to DNA, protein to protein, and protein to DNA; additionally, the choice depends on whether the comparison is between pairs of sequences (in which case GAP or BestFit are generally preferred) or between one sequence and a large database of sequences (in which case FASTA or BLASTA are preferred).

15 Certain alignment schemes for aligning two amino acid sequences may result in matching of only a short region of the two sequences, and this small aligned region may have very high sequence identity even though there is no significant relationship between the two full-length sequences. Accordingly, in a preferred embodiment, the selected alignment method will result in an alignment that spans at least 66
20 contiguous amino acids of the claimed full-length polypeptide.

A polypeptide also may be considered homologous to a PAL polypeptide of the invention if polynucleotides encoding the two polypeptides hybridize with one another. A higher degree of homology is shown if the hybridization occurs under hybridization conditions of greater stringency. Control of hybridization conditions
25 and the relationships between hybridization conditions and degree of homology are understood by those skilled in the art (see, e.g., Sambrook et al. (Eds.), *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory Press: Cold Spring Harbor, New York, pp. 9.47 to 9.51 (1989)), and are as previously described, and as described in the examples that follow. Thus, a homologous polypeptide may be a
30 polypeptide that is encoded by a polynucleotide that hybridizes with a polynucleotide encoding a polypeptide of the invention under hybridization conditions having a

specified degree of stringency. Relationships based on hybridization as just described do not result in a particular “identity” or “similarity” value being assigned to compared polypeptides, but such a value generally can be inferred.

It also may be desirable that such structurally homologous polypeptides will exhibit functional homology, insofar as the homologous polypeptide has substantially the same function as the polypeptide of the invention. Structurally homologous polypeptides may be considered functionally homologous if they exhibit similar biological activity. Generally, if 24 out of 80 appropriately aligned residues (*i.e.*, 30%; more for shorter matches, Sander et al., *Proteins*, 9, 56-68 (1991)) are identical between two naturally evolved proteins, the two polypeptides/proteins will have similar three-dimensional structures and similar functions (Chothia et al., *EMBO J.*, 5, 823-826 (1986); Feng et al., *J. Mol. Evol.*, 21, 112-125 (1985)).

On the other hand, it is also known that two polypeptides or two polynucleotides can be considered to be substantially homologous in structure, and yet differ substantially in function. For example, single nucleotide polymorphisms (SNPs) among alleles may be expressed as polypeptides having substantial differences in function along one or more measurable parameters such as antibody- or ligand-binding affinity or enzymatic substrate specificity, and the like. Other structural differences, such as substitutions, deletions, splicing variants, and the like, may affect the function of otherwise structurally identical or homologous polypeptides.

The PAL polypeptides of the invention include functional derivatives of the PAL polypeptide defined in SEQ ID NO:13. Such functional derivatives include polypeptide products that possess a structural feature or a biological activity that is substantially similar to a structural feature or a biological activity of the PAL protein. Accordingly, functional derivatives include variants, fragments, and chemical derivatives of the parent PAL protein.

As used herein “variant” refers to a molecule substantially similar in structure and function to either the entire PAL molecule, or to a fragment thereof. A molecule is said to be “substantially similar” to another molecule if both molecules have substantially similar structures and/or if both molecules possess a similar biological

activity. Thus, provided that two molecules possess a similar activity, they are considered variants, as that term is used herein, even if one of the molecules possesses a structure not found in the other molecule, or if the sequence of amino acid residues is not identical. Among the variant polypeptides provided under the invention are variants that comprise one or more changes in the amino acid sequence of the PAL polypeptide. Such sequence-based changes include deletions, substitutions, or insertions in the PAL polypeptide sequence, as well as combinations thereof.

Deletion variants of the PAL polypeptides are polypeptides in which at least one amino acid residue of the sequence is removed. Deletions can be effected at one or both termini of the protein, or with removal of one or more residues within (*i.e.*, internal to) the PAL amino acid sequence. Deletion variants include, for example, all incomplete fragments of the PAL polypeptides of the invention, but particularly, PAL polypeptides comprising deletion of one, two, three, four, five, or six residues at the amino and/or carboxyl terminus. As used herein "fragment" refers to any polypeptide subset of the PAL protein. Such fragments include, for example, fragments comprising particular amino acids of the amino acid sequence defined by SEQ ID NO:13, as well as N-terminally extended fragments of that sequence and C-terminal truncates thereof. Fragments of PAL that exhibit a biological activity characteristic of PAL (*e.g.*, any biological activity characteristics of PAL) are desirable. Identification of such fragments is well known in the art, and is further described herein.

Substitution variants are provided, including polypeptides in which at least one amino acid residue of a PAL polypeptide is removed and replaced by an alternative residue. In one aspect, the substitutions preferably are conservative in nature, however, the invention also embraces substitutions that are non-conservative (*e.g.*, as in cases where an altered biological activity is desired). A conservative substitution is recognized in the art as a substitution of one amino acid for another amino acid that has similar property. Any substitution can be made, with conservative substitutions (as further described herein) being preferred. Directed amino acid substitutions may be made based on well defined physicochemical parameters of the canonical and other amino acids (*e.g.*, the size, shape, polarity,

charge, hydrogen-bonding capacity, solubility, chemical reactivity, hydrophobicity, hydrophilicity, or the amphipathic character of the residues) as well as their contribution to secondary and tertiary protein structure. Substitution variants can include polypeptides comprising one or more conservative amino acid substitutions, *i.e.*, a substitution of one amino acid by another having similar physicochemical character, as desired. To illustrate, the canonical amino acids can be grouped according to the categories below, and conservative substitutions for this purpose can be defined according to these groupings:

10	Aliphatic Side Chains	Gly, Ala; Val, Leu, Ile
	Aromatic Side Chains	Phe, Tyr, Trp
	Aliphatic Hydroxyl Side Chains	Ser, Thr
	Basic Side Chains	Lys, Arg, His
	Acidic Side Chains	Asp, Glu
15	Amide Side Chains	Asn, Gln
	Sulfur-Containing Side Chains	Cys, Met
	Secondary Amino Group	Pro

Substitutions preferably are made in accordance with **Table 1** (below) when it is desired to control the characteristics of the PAL molecule. The conservative substitutions generally include those which are categorized as part of the Clustal W program as showing “strong similarity” or “weak similarity”, as set out in **Table 1**.

TABLE 1		
Original Residue	Exemplary Conservative Substitutions	
	Strong Similarity	Weak Similarity
Ala	Gly; Ser	Cys; Thr; Val
Arg	Lys	Asp; Glu; His; Asn; Gln
Asn	Gln	Asp; Glu; Gly; His; Lys; Arg; Ser; Thr
Asp	Glu	Gly; His; Lys; Asn; Gln; Arg; Ser
Cys		Ala; Ser
Gln	Asn	Asp; Glu; His; Lys; Arg; Ser
Glu	Asp	His; Lys; Asn; Gln; Arg; Ser
Gly	Ala	Asp; Asn; Ser
His	Tyr	Asp; Glu; Phe; Lys; Asn; Gln; Arg
Ile	Leu; Val; Met	Phe
Leu	Ile; Val; Met	Phe
Lys	Arg	Asp; Glu; His; Asn; Gln; Ser; Thr
Met	Leu; Ile; Val	Phe
Phe	Tyr; Trp	His; Ile; Leu; Met
Pro		Ser; Thr
Ser	Thr; Ala	Cys; Asp; Glu; Gly; Lys; Asn; Pro; Gln
Thr	Ser	Ala; Lys; Asn; Pro; Val
Trp	Tyr; Phe	
Tyr	Trp; Phe; His	
Val	Ile; Leu; Met	Ala; Thr

Substantial changes in structure and/or function of a PAL polypeptide are made by selecting conservative substitutions that show only weak similarity (as opposed to strong similarity), or are more progressive than those in **Table 1**, *i.e.*, selecting residues that differ more significantly in their effect on maintaining: (a) the secondary
5 structure of the polypeptide backbone in the area of the substitution, (b) the charge or hydrophobicity of the molecule at the target site, and/or (c) the bulk of the side chain. The substitutions that, in general, are more progressive are those in which: (a) glycine and/or proline is substituted by another amino acid, or is deleted or inserted; (b) a hydrophilic residue is substituted for a hydrophobic residue; (c) a cysteine residue is
10 substituted for (or by) any other residue; (d) a residue having an electropositive side chain is substituted for (or by) a residue having an electronegative charge; and/or (e) a residue having a bulky side chain is substituted for (or by) one not having such a side chain.

Substitution variants, however, also can include non-canonical or non-
15 naturally occurring amino acid residues substituted for amino acid residues in the principal sequence (*e.g.*, as set forth in 37 C.F.R. § 1.822). Substitution variants include those polypeptides in which amino acid substitutions have been introduced by modification of polynucleotides encoding a PAL polypeptide.

Insertion variants also desirably are provided, in which at least one amino acid
20 residue is present in addition to a PAL amino acid sequence (*e.g.*, including a PAL amino acid sequence having deletions and/or substitutions). Insertions may be located at either or both termini of the polypeptide, or may be positioned within (*i.e.*, internal to) the PAL amino acid sequence. Insertion variants also include fusion proteins in which the amino or carboxy terminus of the PAL polypeptide is fused to another
25 polypeptide. Examples of such fusion proteins include but are not limited to immunogenic polypeptides, proteins with a long circulating half-life (*e.g.*, immunoglobulin constant regions), marker proteins (*e.g.*, green fluorescent protein) and proteins or polypeptides that facilitate purification of the desired PAL polypeptide (*e.g.*, FLAG® tags, polyhistidine sequences, and the like). Another example of a
30 terminal insertion is a fusion of a signal sequence, whether heterologous or homologous to the host cell, to the N-terminus of the molecule to facilitate the

secretion of the derivative from recombinant hosts. Intrasequence insertions (*i.e.*, insertions within a PAL molecule sequence) preferably range from about 1 to about 50 residues, more preferably from about 1 to about 10 residues, and most preferably from about 1 to about 5 residues.

5 Polypeptide variants of the invention also include mature PAL products, *e.g.*, PAL products wherein any leader or signal sequences are removed, as well as products having additional amino terminal residues (*e.g.*, one or more additional methionine residue at position -1 or -n). Other such variants are particularly useful for recombinant protein production in prokaryotic or eukaryotic host cells.

10 The invention also encompasses PAL variants having additional amino acid residues resulting from use of specific expression systems. For example, use of commercially available vectors that express a desired polypeptide as a glutathione-S-transferase (GST) fusion product yields the desired polypeptide having an additional glycine residue at position -1 (Gly⁻¹-PAL) upon cleavage of the GST component from
15 the desired polypeptide. Variants that result from expression in other vector systems are also contemplated, as are fusion proteins wherein the amino and/or carboxy termini of a PAL polypeptide is fused to another polypeptide, such as a constant region of an immunoglobulin chain or fragment thereof, or a targeting moiety such as an antibody or antibody fragment.

20 If desired, the polypeptides of the invention can be modified, for instance, by glycosylation, amidation, carboxylation, or phosphorylation, or by the creation of acid-addition salts, amides, esters, in particular C-terminal esters, and N-acyl derivatives of the polypeptides of the invention. The polypeptides also can be modified to create peptide derivatives by forming covalent or noncovalent complexes
25 with other moieties. Covalently-bound complexes can be prepared by linking the chemical moieties to functional groups on the side chains of amino acids comprising the polypeptides, or at the N- and/or C-terminus. Further modifications will be apparent to those of ordinary skill in the art, and are encompassed by the invention.

In particular, the invention provides PAL polypeptide products that are
30 chemical derivatives of the PAL polypeptide defined in SEQ ID NO:13. As used herein, the term "chemical derivative" refers to molecules that contain additional

chemical moieties that are not normally a part of the naturally-occurring molecule. Such moieties desirably can impart desirable properties to the derivative molecule, such as increased solubility, absorption, biological half-life, and the like. Thus, chemical derivatives of PAL polypeptides include polypeptides bearing modifications
5 other than (and/or in addition to) insertion, deletion or substitution of amino acid residues. Preferably, the modifications are covalent in nature, and include, for example, chemical bonding with polymers, lipids, non-naturally occurring amino acids, and other organic and inorganic moieties. In particular, derivatives of the invention preferably can be prepared to increase the ability of a PAL polypeptide to
10 be employed for the production of phenylalanine, phenylalanine analogs, and optically active unnatural amino acids having phenylalanine-like structures.

For example, methods are known in the art for modifying a polypeptide to include one or more water-soluble polymer attachments such as polyethylene glycol, polyoxyethylene glycol, or polypropylene glycol. Particularly preferred are PAL
15 products that have been covalently-modified with polyethylene glycol (PEG) subunits. Water-soluble polymers can be bonded at specific positions, for example at the amino terminus of the PAL products, or randomly attached to one or more side chains of the polypeptide. Additional derivatives include PAL species immobilized on a solid support, pin microparticle, or chromatographic resin, as well as PAL
20 species modified to include one or more detectable labels, tags, chelating agents, and the like.

Derivatization with bifunctional agents can be used to cross-link PAL to a water-insoluble support matrix. Alternatively, reactive water-insoluble matrices such as cyanogen bromide-activated carbohydrates and the reactive substrates described in
25 U.S. Patents 3,969,287; 3,691,016; 4,195,128; 4,247,642; 4,229,537; and 4,330,440 are employed for protein immobilization. Immobilization of PAL may be of particular utility in its purification and/or assay.

Expression of pal variants can be expected to have utility in investigating a biological activity characteristic of a wild-type PAL polypeptide. pal variants can be
30 designed to retain all biological or immunological properties characteristic for PAL, or to specifically disable one or more particular biological or immunological

properties of PAL. For example, fragments and truncates may be designed to delete a domain associated with a particular property, or substitutions and deletions may be designed to inactivate a property associated with a particular domain. Forced expression (overexpression) of such variants ("dominant negative" mutants) can be employed to study the function of the protein *in vivo* in its natural host by observing the phenotype associated with the mutant.

Functional derivatives of PAL having up to about 200 residues may be conveniently prepared by *in vitro* synthesis. If desired, such fragments may be modified using methods known in the art by reacting targeted amino acid residues of the purified or crude protein with an organic derivatizing agent that is capable of reacting with selected side chains or terminal residues. The resulting covalent derivatives may be used to identify residues important for biological activity. Other methods such as are known in the art similarly can be employed.

Functional derivatives of PAL having altered amino acid sequences can also be prepared by mutating the DNA encoding PAL. Any combination of amino acid deletion, insertion, and substitution may be employed to generate the final construct, provided that the final construct possesses the desired activity. Obviously, the mutations that will be made in the DNA encoding the functional derivative must not place the sequence out of reading frame and preferably will not create complementary regions that could produce secondary mRNA structure (see, *e.g.*, EP Patent Publication No. 75,444).

While the site for introducing a variation in the amino acid sequence is predetermined, the mutation *per se* need not be predetermined. For example, to optimize the performance of a mutation at a given site, random mutagenesis, such as linker scanning mutagenesis, can be conducted at a target codon or target region to create a large number of derivatives which could then be expressed and screened for the optimal combination of desired activity. Alternately, site-directed mutagenesis or other well-known techniques may be employed to make mutations at predetermined sites in a DNA known sequence.

The technique of site-directed mutagenesis is well known in the art, as exemplified by publications such as Sambrook et al., *supra*, and McPherson (Ed.),

Directed Mutagenesis: A Practical Approach, IRL Press, Oxford (1991). Site-directed mutagenesis allows the production of pal functional derivatives through use of specific oligonucleotide sequences that encode the DNA sequence of the desired mutation. Site-directed mutagenesis methods and materials are commercially available, e.g., the QuikChange™ kit available from Stratagene (La Jolla CA). One can selectively generate precise amino acid deletions, insertions, or substitutions using this method. Amino acid sequence deletions according to the invention preferably range from about 1 to about 50 residues, more preferably from about 1 to about 30 residues, even more desirably from about 1 to about 10 residues, and typically are contiguous.

Mutations designed to alter the activity of PAL may be guided by the introduction of the amino acid residues that are present at homologous positions in other phenylalanine ammonia lyase proteins (particularly PAL proteins of evolutionarily similar genus/species). It is difficult to predict *a priori* the exact effect any particular modification, e.g., substitution, deletion, insertion, etc., will have on the biological activity of PAL. However, one skilled in the art will appreciate that the effect will be evaluated by routine screening assays. For example, a derivative typically is made by linker scanning site-directed mutagenesis of the DNA encoding the native PAL molecule. The derivative is then expressed in a recombinant host, and, optionally, purified from the cell culture, for example, by immunoaffinity chromatography. The activity of the cell lysate or the purified derivative is then screened in a suitable screening assay for the desired characteristic. For example, a change in the immunological character of the functional derivative, such as affinity for a given antibody, is measured by a competitive type immunoassay. Changes in other parameters of the expressed product may be measured by the appropriate assay.

pal Polynucleotides

The present invention provides, *inter alia*, novel purified and isolated polynucleotides encoding yeast PAL polypeptides. The polynucleotides of the invention include DNA sequences and RNA transcripts, and both sense and complementary antisense strands. DNA sequences of the invention preferably include

cDNA or genomic sequences. "Nucleic acid" as used herein refers to an oligonucleotide or polynucleotide sequence, and fragments or portions thereof, and to DNA or RNA of cellular or synthetic origin (or mixtures thereof), which may be double-stranded or single-stranded, whether representing the sense or antisense strand.

5 The term nucleic acid is used interchangeably with the term "polynucleotide", which can have any length. By comparison, an "oligonucleotide" is a nucleic acid species that has less than about 50 bp. An exemplary double-stranded polynucleotide according to the invention can have a first strand (*i.e.*, a coding strand) having a sequence encoding a PAL polypeptide, along with a second strand (*i.e.*, a
10 "complementary" or "non-coding" strand) having a sequence deducible from the first strand according to the Watson-Crick base-pairing rules for DNA. Double-stranded or "duplex" structures may be DNA:DNA, DNA:RNA, or RNA:RNA nucleic acids. A preferred double-stranded polynucleotide according to the invention is a cDNA having a nucleotide sequence defined by SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or
15 portions thereof) or a genomic DNA having a sequence defined by SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586). An exemplary single-stranded polynucleotide according to the invention is a messenger RNA (mRNA) encoding a PAL polypeptide. Another
20 exemplary single-stranded polynucleotide is an oligonucleotide probe or primer that hybridizes to the coding or non-coding strand of a polynucleotide defined by SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to
25 2586). Other alternative nucleic acid structures, *e.g.*, triplex structures, are also contemplated by the invention.

The PAL cDNA of the invention comprises the protein-coding region for a PAL polypeptide and includes allelic variants of the preferred polynucleotides of the invention, such as single nucleotide polymorphisms of the wild-type gene. Allelic
30 variants are known in the art to be modified forms of the wild-type (predominant) gene sequence, and which similarly are reflected as changes in cDNA from the variant

as compared to cDNA from a wild-type gene. Allelic variants are detected as cDNAs from naturally occurring sequences, as opposed to cDNAs from non-naturally occurring variants, which arise from *in vitro* manipulation.

The invention in particular comprehends cDNA, which is obtained through
5 reverse transcription of a RNA polynucleotide encoding PAL followed by second strand synthesis of a complementary strand to provide a double-stranded DNA (*e.g.*, as described in the Examples which follow). Also, the invention provides genomic DNA encoding PAL. For instance, the invention desirably provides a cDNA sequence that encodes a polypeptide having the amino acid sequence defined by SEQ
10 ID NO:13. The invention also desirably provides a genomic DNA that encodes a polypeptide having the amino acid sequence of SEQ ID NO:13. In preferred embodiments, the invention provides polynucleotides comprising a nucleotide sequence defined by SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or by SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1
15 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586).

As noted, a particularly preferred polynucleotide sequence according to the invention is defined by SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1
20 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586). However, because the genetic code is redundant or "degenerate" in its information-encoding properties, different nucleotide sequences may encode the same polypeptide sequence, as is well known in the art. Accordingly, the invention comprises the alternative (degenerate) nucleotide
25 sequences that encode PAL polypeptides of the invention and functional equivalents thereof. For example, the invention includes polynucleotides comprising nucleotide sequences that are substantially identical to the pal sequence of SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to
30 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586). More particularly, the invention includes polynucleotides whose corresponding

nucleotide sequences have at least 80%, preferably at least 90%, more preferably at least 95%, and still more preferably at least 99% identity with a nucleotide sequence defined in SEQ ID NO:12 (e.g., residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (e.g., residues 1 to 2589 or portions, thereof, particularly residues 1 to 361,
5 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586).

Along these lines, the sequence (e.g., one synthesized in a laboratory) can be partially or wholly theoretical, e.g., obtained by reference to or based on a pal polynucleotide or polypeptide sequence. Exemplary theoretical sequences include the
10 derived consensus set forth in SEQ ID NOS:20 and 21.

In particular, the present invention preferably provides an isolated and purified yeast phenylalanine ammonia lyase polynucleotide comprising the sequence of SEQ ID NO:20, wherein residues 117, 135, 190, 191, 195, 276, 1196 to 1198, 1724 to 1735, 1880, 1881, and 2187 to 2475 are absent, residues 13, 34, 46, 115, 164, 251,
15 266, 315, 330, 333, 340, 348, 423, 450, 456, 468, 555, 570, 675, 681, 716, 723, 783, 921, 1176, 1380, 1383, 1407, 1446, 1449, 1452, 1488, 1542, 1554, 1563, 1617, 1677, 1683, 1776, 1872, 1895, 1950, 1971, and 1976 are B (i.e., are selected from the group consisting of C or G or T (or U)), residues 49, 119, 331, 463, 715, 1270, 1684, 1708, 1762, 1768, 2001, 2145, and 2183 are D (i.e., are selected from the group consisting
20 of A or G or T (or U)), residues 59, 73, 102, 145, 233, 264, 357, 483, 758, 1042, 1241, 1470, 1509, 1690, 1745, 1962, and 2151 are H (i.e., are selected from the group consisting of A or C or T (or U)), residues 51, 57, 144, 168, 201, 312, 405, 475, 963, 1043, 1281, 1308, 1675, 1678, 1681, 1693, 1952, and 2146 are V (i.e., are selected from the group consisting of A or C or G), residues 79, 729, 1710, and 1873 are Y
25 (i.e., are selected from the group consisting of C or T (or U)), residues 84, 199, and 1723 are W (i.e., are selected from the group consisting of A or T (or U)), residues 82, 200, 732, and 744 are S (i.e., are selected from the group consisting of C or G), residues 106, 108, 284, and 743 are M (i.e., are selected from the group consisting of A or C), residue 730 is K (i.e., are selected from the group consisting of G or T (or
30 U)), residues 76 and 77 are A, residues 68, 75, 1855, 1857, 1858, 1860, 1862, and 1874 are C, and residues 69, 1856, 1859, 1861, 1875 are T. The invention further

desirably provides an isolated and purified yeast phenylalanine ammonia lyase polynucleotide comprising the sequence of SEQ ID NO:29.

As used herein, "identity" is a measure that can be used to compare sequences. Identity differs from "homology", which is a conclusion drawn from identity or similarity data that two sequences (*i.e.*, genes) share a common evolutionary history. In particular, identity is the number of positions in an alignment of sequences that have the same residue (*i.e.*, amino acid or nucleic acid). Percent sequence identity with respect to polynucleotides of the invention can be defined as the percentage of nucleotide bases in a candidate sequence that are identical to nucleotides in the pal-
10 encoding sequence after aligning the sequences and introducing gaps, if necessary, to achieve maximum percent sequence identity. Computer software is available (from commercial and public domain sources) for calculating percent identity in an automated fashion. Similarity is the number of positions in an alignment of sequences that have a similar residue (*i.e.*, amino acid residue, this is not done for nucleic acid
15 sequences).

In particular, alignment of nucleotide sequences for purposes of similarity comparisons can be done using, *e.g.*, the standard tools BLAST (Basic Local Alignment Tool, Altschul et al., *Meth. Enzymol.*, 266, 466-480 (1996), or, the nucleotide derivatives of this program, BLASTN (compares a nucleotide query
20 against a nucleotide sequence database), BLASTX (compares the six-frame conceptual translation of a nucleotide query sequence (both strands) against a protein sequence database (Madden et al., *Meth. Enzymol.*, 266, 131-140 (1996)) or FASTA (Pearson, *Proc. Natl. Acad. Sci.*, 85, 2444-2448 (1988)). Other appropriate programs similarly can be employed for sequence alignment and sequence comparison such as
25 is known in the art. A particularly preferred program for making such comparisons is Clustal W.

Variant polynucleotides of the invention further include fragments of the nucleotide sequence defined in SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly
30 residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586) and homologs thereof. The disclosure of

full-length polynucleotides encoding PAL polypeptides makes readily available to the person having ordinary skill in the art every possible fragment of the full-length polynucleotides. For instance, these can be produced by cleavage of the full length protein, or by synthesis of only a portion of the protein (*i.e.*, using recombinant or chemical means). Preferably, fragment polynucleotides of the invention comprise sequences unique to the PAL-encoding nucleotide sequence, and therefore hybridize under highly stringent or moderately stringent conditions only (*i.e.*, specifically) to polynucleotides encoding PAL or fragments thereof containing the unique sequence. Polynucleotide fragments of cDNA sequences of the invention can comprise not only sequences unique to the coding region, but also include fragments of the full-length sequence derived from untranslated sequences (*e.g.*, the leader sequence). Sequences unique to polynucleotides of the invention are recognizable through sequence comparison to other known polynucleotides, and can be identified through use of computer software routinely used in the art, *e.g.*, alignment programs available in public sequence databases, as previously described.

The invention also provides fragment polynucleotides that are conserved in one or more polynucleotides encoding members of the PAL family of polypeptides. Such fragments include sequences characteristic of PAL polypeptides, referred to as "signature" sequences. The conserved signature sequences many times can be discerned following simple sequence comparison of polynucleotides-encoding members of the PAL family. Polynucleotide fragments of the invention can be labeled in a manner that permits their detection, including radioactive and non-radioactive labeling.

Hybridization according to the invention includes the process of forming partially or completely double-stranded nucleic acid molecules through sequence-specific association of complementary single-stranded nucleic molecules. The invention, therefore, further encompasses the use of nucleic acid species that hybridize to the coding or non-coding strands of a polynucleotide that encodes a PAL protein. Preferred hybridizing species hybridize to the coding or non-coding strand of the nucleotide sequence defined by SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof,

particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586). Also encompassed by the present invention are species that would hybridize to a PAL-encoding polynucleotide but for the redundancy of the genetic code, *i.e.*, polynucleotides that encode the same amino acid sequence but rely on different codon usage.

Hybridizing species include, for example, nucleic acid hybridization or amplification probes (*e.g.*, oligonucleotides or polynucleotides) that are capable of detecting nucleotide sequences (*e.g.*, cDNA or genomic sequences) encoding PAL or closely related molecules, such as cDNAs of genomic alleles. The specificity of the probe, *i.e.*, whether it is derived from a highly conserved, conserved, or non-conserved region or domain, and the stringency of the hybridization or amplification conditions (high, intermediate, or low) will determine whether the probe identifies only cDNAs made naturally occurring PAL, or made from related sequences. Probes for the detection of related nucleotide sequences are selected from conserved or highly conserved regions of PAL family members and such probes may be used in a pool of degenerate probes. For the detection of identical nucleotide sequences, or where maximum specificity is desired, oligonucleotide probes are selected from the non-conserved nucleotide regions or unique regions of pal polynucleotides. As used herein, the term "non-conserved nucleotide region" refers to a nucleotide region that is unique to pal disclosed herein and does not occur in related pal family members.

Specificity of hybridization is typically characterized in terms of the degree of stringency of the conditions under which the hybridization is performed. The degree of stringency of hybridization conditions can refer to the melting temperature (T_m) of the nucleic acid binding complex (see, *e.g.*, Berger and Kimmel, "Guide to Molecular Cloning Techniques," *Methods in Enzymology*, Vol. 152, Academic Press, San Diego CA (1987)). "Maximal stringency" typically occurs at about $T_m - 5^\circ\text{C}$ (5°C below the T_m of the probe); "high stringency" at about 5°C to 10°C below T_m ; "intermediate stringency" at about 10°C to 20°C below T_m ; and "low stringency" at about 20°C to 25°C below T_m .

Also, the stringency of hybridization can refer to the physicochemical conditions employed in the procedure. To illustrate, exemplary moderately stringent

hybridization conditions are: hybridization in 3X saline sodium citrate (SSC), 0.1% sarcosyl, and 20 mM sodium phosphate, pH 6.8, at 65°C; and washing in 2X SSC with 0.1% sodium dodecyl sulfate (SDS), at 65°C. Exemplary highly stringent hybridization conditions are: hybridization in 50% formamide, 5X SSC, at 42°C overnight, and washing in 0.5X SSC and 0.1% SDS, at 50°C. It is understood in the art that conditions of equivalent stringency can be achieved through variation of temperature and buffer, or salt concentration as described Ausubel et al., (Eds.), *Current Protocols in Molecular Biology*, John Wiley & Sons (1994), pp. 6.0.3-6.4.10. Modifications in hybridization conditions can be determined empirically or calculated precisely based on the length of the oligonucleotide probe and the percentage of guanosine/cytosine (GC) base pairing of the probe. The hybridization conditions can be calculated as described in Sambrook et al., (Eds.), *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory Press: Cold Spring Harbor, New York (1989), pp. 9.47-9.51.

The artisan will appreciate that hybridization under more stringent conditions enables the identification of species having a higher degree of homology or sequence identity with the target sequence. By contrast, hybridization under less stringent conditions enables identification of species having a lesser but still significant degree of homology or sequence identity with the target sequence. Therefore, also included within the scope of the present invention are nucleic acid species that are capable of hybridizing to the nucleotide sequence of SEQ ID NO:12 (e.g., residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (e.g., residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586) under conditions of intermediate (moderate) to maximal stringency. Preferably, the hybridizing species hybridize to the coding or non- coding strands of a polynucleotide defined by SEQ ID NO:12 (e.g., residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (e.g., residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586) under highly stringent conditions.

The polynucleotides of the invention include polynucleotides (*i.e.*, nucleic acid species of any length) and oligonucleotides (*i.e.*, nucleic acid oligomers typically from about 5 to about 50 nucleotides in length) that hybridize to either the coding or the non-coding strands of a nucleic acid (*e.g.*, a cDNA or genomic DNA) encoding a PAL amino acid sequence. In particular, the invention comprises polynucleotides and oligonucleotides that hybridize to the coding or non-coding strand of a polynucleotide defined by SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586). A length of the polynucleotide or oligonucleotide is preferred such that the polynucleotide or oligonucleotide is capable of hybridizing to the target nucleic acid molecule. With use of an oligonucleotide for hybridization, desirably the oligonucleotide should not be longer than necessary. Accordingly, desirably the oligonucleotide should contain at most from about 30 to 50 nucleotides, preferably at most from about 20 to about 25 nucleotides, and more preferably at most from about 10 to about 15 nucleotides. With use of a polynucleotide for hybridization, optionally a pal fragment contained within a vector can be employed in its entirety for hybridization. Such polynucleotides and oligonucleotides may be used as described herein as primers for DNA synthesis (*e.g.*, as primers in PCR; “amplimers”), as probes for detecting the presence of target DNA in a sample (*e.g.*, northern or Southern blots and *in situ* hybridization), as therapeutic agents (*e.g.*, in antisense therapy), or for other purposes. Oligonucleotides can be single- or double-stranded, with the double-stranded forms having one or both ends blunted or stepped.

The oligonucleotides may be obtained or derived by known methods from natural sources. Alternatively, the oligonucleotides may be produced synthetically according to methods known in the art. Such methods include, for example, cloning and restriction of appropriate sequences or direct chemical synthesis by any suitable method, such as the phosphotriester method (*e.g.*, see Narang *et al.*, *Methods Enzymol.*, 68, 90 (1979)); the phosphodiester method (*e.g.*, Brown *et al.*, *Methods Enzymol.*, 68, 109 (1979)); the diethylphosphoramidite method (*e.g.*, Beaucage *et al.*,

Tetrahedron Lett., 22, 1859 (1981)); the solid support method (*e.g.*, U.S. Patent 4,458,066); and any other appropriate method.

A preferred source for isolation of a polynucleotide that encodes PAL is strain ATCC PTA-2224, as described in Example 5. The present invention accordingly
5 further provides an isolated and purified yeast polynucleotide that encodes a yeast phenylalanine ammonia lyase polypeptide, wherein the polynucleotide preferably is obtained from strain ATCC PTA-2224. The present invention also desirably provides an isolated and purified yeast polynucleotide that encodes the sequence of SEQ ID NO:13, wherein the polynucleotide is obtained from strain ATCC PTA-2224. The
10 invention further preferably provides an isolated and purified yeast polynucleotide that has the coding sequence specified in SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586), and encodes a yeast
15 phenylalanine ammonia lyase polypeptide, preferably wherein the polynucleotide is obtained from strain ATCC PTA-2224.

The *pal* polynucleotides of the invention include variants, which are polynucleotides that encode PAL or a functional equivalent thereof, and which can include deletions, insertions, or substitutions of nucleotide residues. As used herein a
20 "deletion" is a change in a nucleotide or amino acid sequence in which one or more nucleotides or amino acid residues, respectively, are absent. As used herein an "insertion" or "addition" is a change in a nucleotide or amino acid sequence that results in the addition of one or more nucleotides or amino acid residues, respectively. As used herein a "substitution" is a change in a nucleotide or amino acid sequence in
25 which one or more nucleotides or amino acids are replaced by different nucleotides or amino acids, respectively.

Polynucleotide variants also included within the scope of the present invention are alleles or alternative naturally occurring forms of *pal* sequences (*e.g.*, *pal* cDNA or genomic sequences corresponding to *pal* genes found in nature). Alleles result from
30 naturally occurring mutations, *i.e.*, deletions, insertions or substitutions, in the genomic nucleotide sequence, which may or may not alter the structure or function or

the expressed polypeptides. Each of these types of mutational changes may occur alone, or in combination with the others, one or more times in a given allelic sequence. Single nucleotide polymorphisms (SNPs) may occur, in which a single base mutation may define an altered polypeptide, which in turn may be associated with an overt phenotypic difference. Of course, SNPs may be silent, as they may not change the encoded polypeptide, or any change they do encode may have no effect on phenotype. These changes at the gene level can be reflected in cDNA sequences obtained according to the invention.

The invention further embraces natural homologs of the yeast pal DNA that occur in other yeast species, preferably other species of *Rhodotorula*, and more preferably other microbial species. Such species homologs, in general, share significant homology at the nucleotide level within the protein-coding regions of pal from *R. graminis*. Thus, the invention encompasses polynucleotides that share at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, at least 98%, or at least 99% nucleotide identity with the protein-coding region of a polynucleotide encoding a *R. graminis* PAL polypeptide, e.g., the polynucleotide defined by SEQ ID NO:12 (e.g., residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (e.g., residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586). Percent sequence "identity" with respect to polynucleotides of the invention can be defined as the percentage of nucleotide bases in a candidate sequence that are identical to nucleotides in the pal-encoding sequence after aligning the sequences and introducing gaps, if necessary, to achieve maximum percent sequence identity. Computer software is available (from commercial and public domain sources) for calculating percent identity in an automated fashion.

The invention includes polynucleotides that have been engineered to selectively modify the cloning, processing, and/or expression of the product encoded by the pal polynucleotide sequence. Mutations may be introduced using techniques well known in the art, e.g., site-directed mutagenesis to insert new restriction sites, to alter glycosylation patterns, or to change codon preferences inherent in the use of certain expression systems, while simultaneously maintaining control of the amino

acid sequence of the expressed polypeptide product. For example, codons preferred by a particular prokaryotic or eukaryotic host cell can be selected to increase the rate of pal polynucleotide expression or to produce recombinant RNA transcripts having desirable properties, such as longer half-lives.

5 The pal polynucleotides can be synthesized, wholly or partly, using chemical methods well known in the art. "Chemically synthesized," as used herein and is understood in the art, refers to purely chemical, as opposed to enzymatic, methods for producing polynucleotides. "Wholly" chemically synthesized polynucleotide sequences are therefore produced entirely by chemical means; "partly" chemically
10 synthesized polynucleotides embrace those wherein only portions of the resulting nucleic acid were produced by chemical means. Suitable chemical methods for synthesizing DNA have been described, *e.g.*, by Caruthers, *Science*, 230, 281-285 (1985), as well as numerous other references.

 According to the invention, pal polynucleotides molecules may be modified to
15 increase intracellular stability and half-life. Possible modifications include, but are not limited to, the addition of flanking sequences of the 5' and/or 3' ends of the molecule or the use of phosphorothioate or 2' O-methyl rather than phosphodiester linkages within the backbone of the molecule. Other modifications such as are known in the art are encompassed by the invention.

20 The invention also provides pal peptide nucleic acid (PNA) molecules. These pal PNAs are informational molecules that have a neutral "peptide-like" backbone with nucleobases that allow the molecules to hybridize to complementary pal-encoding DNA or RNA with higher affinity and specificity than corresponding oligonucleotides. Such PNA molecules find particular utility in *in vitro* applications.

25

A Construct According to the Invention

 The invention also provides a construct, *e.g.*, a construct comprising or encoding a PAL polypeptide sequence according to the invention. A "construct" is any form of molecule in which a polypeptide sequence according to the invention or
30 its encoding polynucleotide sequence is joined to or forms part of a larger molecule. The connection between the pal polynucleotide and/or PAL polypeptide sequence and

its site of attachment in the molecule preferably can be by a noncovalent bond (*e.g.*, as in antibody/antigen binding), or by a covalent bond.

Along these lines, a "construct" includes, but is not limited to a vector (*e.g.*, having genetic incorporation of a polypeptide coding sequence into a polynucleotide vector), or a conjugate-type vector (*e.g.*, wherein a coding sequence, polypeptide sequence, or other moiety is noncovalently associated with a vector), or other appropriate moiety that can be employed for effecting cell entry. As used herein a "vector" is a vehicle capable of effecting entry into a cell, *e.g.*, particularly for gene transfer, and has the general meaning of that term as understood by those of skill in the art. Preferably a vector according to the invention comprises a nucleic acid sequence that encodes a PAL polypeptide according to the invention. Optionally, the nucleic acid coding sequence can be so arranged on the vector as to form, upon translation, a fusion protein or antibody fusion (*e.g.*, by juxtaposition of the coding sequence with other coding sequences).

The vectors according to the invention include, but are not limited to, plasmids, phages, and viruses. In particular, desirably the vector comprises a nucleic acid sequence that encodes a PAL polypeptide sequence (*i.e.*, SEQ ID NO:13), as further described herein. The vectors according to the invention are not limited to those that can be employed solely for intracellular delivery, but also include intermediary-type vectors (*e.g.*, "transfer vectors") that can be employed in the construction of other vectors, for instance, in the construction of other vectors that are used in the construction of those vectors that are actually employed to contact cells.

In terms of a viral vector (particularly a retroviral vector, especially a replication-deficient viral vector), such a vector can comprise either complete capsids (*i.e.*, including a viral genome such as a retroviral genome) or empty capsids (*i.e.*, in which a viral genome is lacking, is incomplete, or is degraded, *e.g.*, by physical or chemical means). Preferably the viral vector comprises complete capsids, *i.e.*, as a means of carrying one or more moieties. Since methods are available for transferring viruses, plasmids, and phages in the form of their nucleic acid sequences (*i.e.*, RNA or DNA), a vector similarly can comprise RNA or DNA, in the absence of any associated protein such as capsid protein, and in the absence of any envelope lipid.

Similarly, since liposomes effect cell entry by fusing with cell membranes, a vector can comprise liposomes, with nucleic acids encoding the coat protein. Such liposomes are commercially available, for instance, from Life Technologies, Bethesda, Md. (now Invitrogen, Carlsbad, CA), as well as from other vendors, and can be used according to the recommendations of the manufacturer. The PAL polypeptide or pal polynucleotide (as produced using methods described herein) can be added to the liposomes either after the liposomes are prepared according to the manufacturer's instructions, or during the preparation of the liposomes.

As stated previously, a PAL polypeptide according to the invention can comprise a fusion protein or antibody fusion. Such a fusion protein or antibody fusion can be produced by means of a vector, *e.g.*, wherein the PAL polypeptide encoding sequence, optional spacer sequence, and further peptide sequence, are in their nucleic acid form, and are operably linked so as to form a "passenger gene". Preferably a passenger gene is capable of being expressed in a cell in which the vector has been internalized. A "spacer" sequence is an optional sequence that desirably can be employed to ensure the appropriate spacing of nucleic acid sequences. Preferably the spacer can comprise either coding or noncoding DNA, and desirably comprises from about 1 to about 1000 bp, preferably from about 1 to about 100 bp, and even more preferably from about 1 to about 10 bp.

A "nucleic acid" is a polynucleotide (DNA or RNA). A "gene" is any nucleic acid sequence coding for a protein or a nascent RNA molecule. A "gene product" is either an as yet untranslated RNA molecule transcribed from a given gene or coding sequence (*e.g.*, mRNA or antisense RNA) or the polypeptide chain (*i.e.*, protein or peptide) translated from the mRNA molecule transcribed from the given gene or coding sequence. Whereas a gene can comprise coding sequences plus any non-coding sequences (*e.g.*, introns, and optionally regulatory sequences such as promoters and the like), a "coding sequence" or "coding region" does not include any non-coding (*e.g.*, regulatory) DNA. The coding sequence of the pal genomic DNA is interrupted by introns. A gene or coding sequence is recombinant if the sequence of bases along the molecule has been altered from the sequence in which the gene or coding sequence is typically found in nature, or if the sequence of bases is not

typically found in nature. According to this invention, a gene or coding sequence can be wholly or partially synthetically made, can comprise genomic or complementary DNA (cDNA) sequences, and can be provided in the form of either DNA, PNA (peptide nucleic acid), or RNA.

5 Non-coding sequences or regulatory sequences include (but are not limited to) promoter sequences. A "promoter" is a DNA sequence that directs the binding of RNA polymerase and thereby promotes RNA synthesis. "Enhancers" are cis-acting elements of DNA that stimulate or inhibit transcription of adjacent genes. An enhancer that inhibits transcription is also termed a "silencer". Enhancers differ from
10 DNA-binding sites for sequence-specific DNA binding proteins found only in the promoter (which are also termed "promoter elements") in that enhancers can function in either orientation, and over distances of up to several kilobase pairs, even from a position downstream of a transcribed region. According to the invention, a coding sequence is "operably linked" to a promoter (*e.g.*, when both the coding sequence and
15 the promoter constitute a passenger gene) when the promoter is capable of directing transcription of that coding sequence.

The foregoing describes standard experiments that are easily done by and well known to one skilled in the art. Automated equipment for polypeptide or DNA synthesis is commercially available. Host cells, cloning vectors, DNA expression
20 controlling sequences, oligonucleotide linkers, and other reagents and components are also commercially available.

Method of Intracellular Delivery

The PAL polynucleotide and/or polypeptide sequences of the invention
25 optionally can be introduced intracellularly for various applications (as well as to facilitate production and isolation of PAL). According to the invention, a cell can be any cell, and, preferably, is either a eukaryotic cell or a prokaryotic cell. A eukaryotic cell is a cell which possesses a nucleus surrounded by a nuclear membrane. Preferably for *in vitro* applications (*e.g.*, industrial applications), the eukaryotic cell is
30 of a unicellular species (*e.g.*, a unicellular yeast cell), and, for therapeutic/diagnostic applications (*e.g.*, *in vivo* applications) is a mammalian (optimally, human) cell.

Cells that can be employed for applications other than industrial applications thus include, but are not limited to, a wide variety of different cell types such as avian cells, and mammalian cells including but not limited to rodent, primate (such as chimpanzee, monkey, ape, gorilla, orangutan, or gibbon), feline, canine, ungulate (such as ruminant or swine), as well as, in particular, human cells. For *in vitro* applications including industrial applications, the cell preferably is any species of *Escherichia*, *Bacillus*, *Schizosaccharomyces*, *Pichia*, *Saccharomyces*, *Streptomyces*, *Pseudomonas*, *Erwinia*, and *Clostridia*, and desirably the cell is a yeast cell. For industrial applications, it particularly is preferred that that host organism is an industrial strain (*i.e.*, a production strain), such as an industrial strain of *Escherichia coli*, *Bacillus subtilis*, *Pichia pastoris*, *Saccharomyces cerevisiae*, *Schizosaccharomyces pombe*, *Pseudomonas putida*, *Erwinia chrysanthemi*, *Bacillus stearothermophilus*, *Erwinia* sp., *Clostridia* sp., *Rhodospiridium*, *Toruloides*, and the like. Desirably a cell is one in which the pal polynucleotide sequence is stably maintained, or at least is maintained for a period of time (*i.e.*, typically from anywhere up to three months, and potentially even after three months, including indefinitely) after entry into the cell. Optimally, nascent RNA is transcribed from the pal sequences, as further described herein.

A cell thus can be present as a single entity, or can be part of a larger collection of cells. Such a "larger collection of cells" can comprise, for instance, a cell culture (either mixed or pure), a tissue (*e.g.*, muscle or other tissue), an organ (*e.g.*, heart, lung, liver, gallbladder, urinary bladder, eye, and other organs), an organ system (*e.g.*, skeletal system, circulatory system, respiratory system, gastrointestinal system, urinary system, nervous system, integumentary system or other organ system), or an organism (*e.g.*, a bird, non-human mammal, human, or the like).

The method by which introduction into a cell of a construct, polypeptide, or polynucleotide according to the invention is accomplished comprises contacting the cell with the moiety, preferably so as to result in a cell having it transferred therein. Such "contacting" can be done by any means known to those skilled in the art, and described herein, by which the apparent touching or mutual tangency of the cell and the moiety can be effected. For instance, contacting can be done by mixing these

elements in a small volume of the same solution. Alternately, the cell and the moiety need not necessarily be brought into contact in a small volume, as, for instance, in cases where the construct, polypeptide or polynucleotide is administered to a host, and travels within the host by the bloodstream or other bodily fluid.

5 The method of the present invention can be employed to contact cells that are located either *in vitro* or *in vivo*, for instance for research, diagnosis, or therapy (*e.g.*, reduction of PKU), or for industrial uses (*e.g.*, manufacture of phenylalanine, phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures). According to the invention "contacting" comprises any
10 means by which a product is introduced intracellularly; the method is not dependent on any particular means of introduction and is not to be so construed. Means of introduction are well known to those skilled in the art, and also are exemplified herein.

 Accordingly, introduction of the products of the invention (*e.g.*, vectors,
15 compositions, polynucleotides and/or polypeptides) can be effected, for instance, either *in vitro* (*e.g.*, in an *ex vivo* type method of gene therapy or in tissue culture studies) or *in vivo* by electroporation, transformation, transduction, conjugation or triparental mating, (co)transfection, (co-)infection, membrane fusion with cationic lipids, high velocity bombardment with DNA-coated microprojectiles, incubation
20 with calcium phosphate-DNA precipitate, direct microinjection into single cells, and the like. Similarly, the products can be introduced by means of cationic lipids, *e.g.*, liposomes. Such liposomes are commercially available (*e.g.*, Lipofectin[®], Lipofectamine[™], and the like, supplied by Life Technologies, GIBCO BRL, Gaithersburg, Md. (now Invitrogen, Carlsbad, CA), and other commercial vendors).
25 Also, low levels of the polynucleotides and/or polypeptides may spontaneously be taken up by the cells. Other methods also are available and are known to those skilled in the art.

 One skilled in the art will appreciate that suitable methods of administering a product of the present invention to an animal (*e.g.*, a human) for purposes of gene
30 therapy, chemotherapy, cell marking, and the like are available, and, although more than one route can be used for administration, a particular route can provide a more

immediate and more effective reaction, or a more convenient or less invasive means, than another route.

PAL Polypeptide Production Systems

5 Knowledge of PAL-encoding DNA sequences enables the artisan to modify cells to permit or increase production of PAL. Accordingly, host cells are provided, including prokaryotic or eukaryotic cells, either stably or transiently modified by introduction of a polynucleotide of the invention to permit expression of the encoded PAL polypeptide, or stably or transiently modified by introduction of a PAL
10 polypeptide. In particular, these cell systems desirably can be used for the production of PAL polypeptide. With use of industrial host cells (*i.e.*, host cells adapted for high level production of polypeptide under industrial conditions, the cells optimally can be employed in industrial fermentation reactions, *e.g.*, for the production of phenylalanine, phenylalanine analogs, and other optically active unnatural amino
15 acids having phenylalanine-like structures.

The form in which PAL-encoding polynucleotides and PAL polypeptides are introduced into cells is further described above as a “construct” according to the invention. In particular, the invention desirably provides autonomously replicating recombinant expression constructs such as plasmid and viral DNA vectors
20 incorporating PAL-encoding sequences.

The invention further desirably provide expression constructs comprising PAL-encoding polynucleotides operatively linked to an endogenous or exogenous expression control DNA sequence and a transcription terminator. Expression control DNA sequences include promoters, enhancers, and operators, and are generally
25 selected based on the expression systems in which the expression construct is to be used. Preferred promoter and enhancer sequences are generally selected for the ability to increase gene expression, while operator sequences are generally selected for the ability to regulate gene expression. Preferred constructs of the invention also include sequences necessary for replication in a host cell. Expression constructs are
30 preferably used for production of an encoded PAL polypeptide, but may also be used to amplify the construct itself.

Thus, polynucleotides of the invention may be introduced into the host cell desirably as part of a circular plasmid, or as linear DNA comprising an isolated protein coding region, contained on a viral vector, or by any other appropriate means. Methods for introducing DNA in to a host cell include transformation, transfection, electroporation, nuclear injection, or fusion with carriers such as liposomes, micelles, ghost cells, and protoplasts, to name but a few.

Any appropriate expression vector (e.g., as described in Pouwels et al., *Cloning Vectors: A Laboratory Manual* (Elsevier, N.Y.: 1985)) and corresponding suitable host can be employed for production of polypeptides/proteins according to the invention. Expression hosts include, but are not limited to, bacteria, yeast, fungal, mammalian, plant, and insect host cell systems including baculovirus systems (e.g., as described by Luckow et al., *Bio/Technology*, 6, 47 (1988)) to name but a few, and established cell lines such as the COS-7, C127, 3T3, CHO, HeLa, BHK cell line, and the like. Some suitable prokaryotic host cells include, but are not limited to, for example, *E. coli* strains SG-936, HB 101, W3110, X1776, X2282, DHI, and MRC1, *Pseudomonas* species, *Bacillus* species such as *B. subtilis*, *Salmonella* and *Streptomyces* species. Suitable eukaryotic host cells include yeasts, such as *Saccharomyces cerevisiae*, *Schizosaccharomyces pombe*, *Pichia pastoris* and other fungi, insect cells such as sf9 or sf21 cells (*Spodoptera frugiperda*), animal cells such as Chinese hamster ovary (CHO) cells, yeast cells such as JY, 293, and NIH3T3 cells, plant cells such as *Arabidopsis thaliana* cells, as well as any other appropriate cell, especially those previously described herein (section entitled "Method of Intracellular Delivery") for *in vitro* applications including industrial applications. The pal nucleotide sequence, or any portion of it, may be cloned into a vector for the production of an mRNA probe. Such vectors are known in the art, are commercially available, and may be used to synthesize RNA probes *in vitro* by addition of labeled nucleotides and an appropriate RNA polymerase such as T7, T3, or SP6.

The ordinary skilled artisan is, of course, aware that the choice of expression host has ramifications for the type of polypeptide/protein produced. For instance the glycosylation of peptides produced in yeast or mammalian cells (e.g., COS-7 cells) will differ from that of peptides produced in bacterial cells such as *Escherichia coli*.

The type of host cell, the form of the expressed PAL product, the conditions of growth, and the like, can be selected by the skilled artisan according to known criteria. Use of microbial host cells, particularly yeast host cells, is expected to provide for such post-translational modifications (*e.g.*, glycosylation, truncation, lipidation, and phosphorylation) as may be needed to confer optimal biological activity on recombinant expression products of the invention. Glycosylated and non-glycosylated forms of PAL polypeptides are embraced. The protein produced by a recombinant cell preferably may be secreted or may be contained intracellularly, depending on the sequence and/or the vector used. As will be understood by those of skill in the art, expression vectors containing *pal* polynucleotide sequences can be designed with signal sequences that direct secretion of PAL through a particular prokaryotic or eukaryotic cell membrane.

Similarly, in the different hosts, the nature of the non-coding DNA upstream of the *pal* coding region should be composed of transcription/translation signals appropriate for the host. Optimally, transcriptional signals such as those of *S. cerevisiae* phosphoglycerate kinase and mating factor genes should be placed 5' to the ribosome binding site. The construct employed optionally can use standard replicons (*e.g.*, 2 μ m) and selectable markers (*e.g.*, *Leu2*, *Trp*, and the like) to select for continued maintenance of the construct. For use in *E. coli*, well known promoters such as lambda PL, *tac*, *trp*, *rac*, or *lac*, as well as others, optionally can be employed, preferably with use of appropriate bacterial ribosome binding sites. For such constructs, optionally *ColEI*, RSF1010, and RI (runaway) replicons can be employed.

Host cells of the invention are useful in methods for large-scale production or use of PAL polypeptide products. For example, recombinant PAL can be produced and isolated from host cells for use in *in vitro* binding assays such as drug screening assays. In such methods, the host cells are grown in a suitable culture medium and the desired polypeptide product is isolated from the cells or from the medium in which the cells are grown. Such host cells (*e.g.*, industrial or producing strains) similarly can be employed in industrial fermentation cultures for producing phenylalanine, phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures.

The polypeptide product optionally can be isolated by purification methods known in the art, and as described in the following examples, and including such conventional chromatographic methods such as immunoaffinity chromatography, receptor affinity chromatography, hydrophobic interaction chromatography, lectin
5 affinity chromatography, size exclusion filtration, cation or anion exchange chromatography, high performance liquid chromatography (HPLC), reverse- phase HPLC, and the like.

Still other methods of purification include those in which the desired protein is expressed and purified as a fusion protein in which the PAL polypeptide is ligated to a
10 heterologous amino acid sequence. Suitable heterologous sequences can include a specific tag, label, or chelating moiety that is recognized by another agent. For example, it is possible to produce a PAL protein fused to a selected heterologous protein selected to be specifically identifiable. A fusion protein also may be engineered to contain a cleavage site (*e.g.*, a factor XA or enterokinase sensitive
15 sequence) located between the PAL sequence and the heterologous protein sequence, to permit the PAL protein to be cleaved from the heterologous protein and subsequently purified. Cleavage of the fusion component may produce a form of the desired protein having additional amino acid residues resulting from the cleavage process.

20 Exemplary heterologous peptide domains include metal-chelating peptides such as histidine-tryptophan modules that allow purification on immobilized metals (Porath, *Protein Expr. Purif.*, 3:263-281 (1992)), and protein A domains that allow purification on immobilized immunoglobulin. Another useful system is the divalent cation-binding domain and antibodies specific thereto used in the peptide
25 extension/immunoaffinity purification system, for instance, as described in U.S. Patents 4,703,004, 4,782,137, 4,851,431, and 5,011,912. This system is commercially available as the FLAG® system from Immunex Corp. (Seattle WA). Another suitable heterologous fusion partner is glutathione *S*-transferase (GST), which can be affinity purified using immobilized glutathione. Other useful fusion partners include
30 immunoglobulins and fragments thereof, *e.g.*, Fc fragments.

Identification of host cells expressing recombinant PAL in certain instances may be helpful in identifying appropriate expression systems. Accordingly, expression constructs of the invention may also include sequences encoding one or more selectable markers that permit identification of host cells bearing the construct in operative condition. It is also contemplated that, in addition to the insertion of heterologous promoter DNA, amplifiable marker DNA (*e.g.*, *ada*, *dhfr*, and the multifunctional CAD gene that encodes carbamyl phosphate synthase, aspartate transcarbamylase, and dihydroorotase, to name but a few) and/or intron DNA may be inserted along with the heterologous promoter DNA. If linked to the PAL-encoding sequence, amplification of the marker DNA by standard selection methods results in co-amplification of the PAL-encoding sequences in the cells. Detection of expression of the marker gene in response to induction or selection usually indicates expression of *pal* as well. Alternatively, if the *pal* polynucleotide is inserted within a marker gene sequence, recombinant cells containing *pal* can be identified by the absence of marker gene function.

Host cells that contain the coding sequence for PAL and that express *pal* also may be identified by a variety of other procedures known to those of skill in the art. These procedures include, but are not limited to, PCR amplification, hybridization, enzyme assay, or immunoassay techniques, that include membrane-based, solution-based, or chip-based technologies for the detection and/or quantification of the nucleic acid or protein. For measuring PAL activity, preferably an enzyme assay is performed.

The presence of the *pal* polynucleotide sequence can be detected by DNA-DNA or DNA-RNA hybridization or amplification using fragments of *pal* disclosed in SEQ ID NO:12 (*e.g.*, residues 37 to 2196 or portions thereof) or SEQ ID NO:28 (*e.g.*, residues 1 to 2589 or portions, thereof, particularly residues 1 to 361, 449 to 880, 961 to 1295, 1365 to 1529, 1587 to 1748, 1822 to 1947, 2008 to 2589, and/or residues 2008 to 2586) as probes. Nucleic acid amplification-based assays involve the use of oligonucleotides based on the *pal* sequence to detect transformants containing *pal* DNA or RNA. Labeled hybridization or PCR probes for detecting *pal* polynucleotide

sequences can be made by various methods, including oligolabeling, nick translation, and end-labeling. Pal polynucleotides preferably are detected by PCR amplification.

In one embodiment of the present invention, PAL or a variant thereof and/or a host cell line that expresses the PAL or variant thereof may be used to screen for antibodies, peptides, or other molecules, such as organic or inorganic molecules, that act as modulators of a biological or immunologic activity of PAL. For example, anti-PAL antibodies capable of neutralizing the activity of PAL may be used *in vivo* (i.e., in yeast cells or others) to inhibit PAL-mediated activity. Alternatively, screening of peptide libraries or organic libraries made by combinatorial chemistry with recombinantly expressed pal or variants thereof, or cell lines expressing PAL or variants thereof, may be useful for identification of therapeutic molecules that function by modulating a biological or immunologic activity of PAL. Synthetic compounds, natural products, and other sources of potentially biologically active materials can be screened in a number of ways deemed routine by those of skill in the art.

PAL Polynucleotide and Polypeptide Probes

The present invention further provides a method of detecting the presence of a PAL-encoding polynucleotide or a PAL polypeptide in a sample. The method involves use of a labeled probe that recognizes the presence of a defined target in the sample. The probe preferably is an antibody that recognizes a PAL polypeptide, or an oligonucleotide (or polynucleotide) that recognizes a polynucleotide encoding PAL polypeptide.

The probes of the invention can be detectably labeled in accordance with methods known in the art. In general, the probe can be modified by attachment of a detectable label (reporter) moiety to the probe, or a detectable probe can be manufactured with a detectable label moiety incorporated therein. The detectable label moiety can be any detectable moiety, many of which are known in the art, including radioactive atoms, electron dense atoms, enzymes, chromogens and colored compounds, fluorogens and fluorescent compounds, members of specific binding pairs, and the like.

Methods for labeling oligonucleotide probes have been described, for example, by Leary et al., *Proc. Natl. Acad. Sci., USA*, 80:4045 (1983) ; Renz and Kurz, *Nucleic Acids Res.*, 12:3435 (1984); Richardson and Gumpert, *Nucleic Acids Res.*, 11:6167 (1983); Smith et al., *Nucleic Acids Res.*, 13:2399 (1985); Meinkoth and Wahl, *Anal Biochem.*, 138:267 (1984). Other methods for labeling polynucleotides are described, for example, in U.S. Patent Nos. 4,711,955, 4,687,732, 5,241,060, 5,244,787, 5,328,824, 5,580,990, and 5,714,327, and still further methods such as are known in the art can be employed.

Methods for labeling antibodies have been described, for example, by Hunter et al. (1962) and by David et al., *Biochemistry*, 13:1014-1021 (1974). Additional methods for labeling antibodies have been described in U.S. Patents 3,940,475 and 3,645,090.

The label moiety according to the invention preferably is radioactive. Some examples of useful radioactive labels include ^{32}P , ^{125}I , ^{131}I , and ^3H . Use of radioactive labels has been described in U.K. patent document No. 2,034,323, and U.S. Patents 4,358,535, and 4,302,204.

Some examples of non-radioactive labels that can be employed include, but are not limited to, enzymes, chromogens, atoms and molecules detectable by electron microscopy, and metal ions detectable by their magnetic properties.

Some useful enzymatic labels include enzymes that cause a detectable change in a substrate. Some useful enzymes (and their substrates) include, for example, horseradish peroxidase (pyrogallol and o-phenylenediamine), beta-galactosidase (fluorescein beta-D-galactopyranoside), and alkaline phosphatase (5-bromo-4-chloro-3-indolyl phosphate/nitro blue tetrazolium). The use of enzymatic labels has been described, for example, in U.K. 2,019,404, EP 63,879, and by Rotman, *Proc. Natl. Acad. Sci. USA*, 47:1981-91 (1961). Other enzymatic labels similarly can be employed in the invention.

Useful reporter moieties include (but are not limited to), for example, fluorescent, phosphorescent, chemiluminescent, and bioluminescent molecules, as well as dyes. Some specific colored or fluorescent compounds useful in the present invention include, for example, fluoresceins, coumarins, rhodamines, Texas red,

phycoerythrins, umbelliferones, Luminol®, and the like. Chromogens or fluorogens, *i.e.*, molecules that can be modified (*e.g.*, oxidized) to become colored or fluorescent or to change their color or emission spectra, are also capable of being incorporated into probes to act as reporter moieties under particular conditions.

5 The label moieties may be conjugated to the probe by methods that are well known in the art. The label moieties may be directly attached through a functional group on the probe. The probe either contains or can be caused to contain such a functional group. Some examples of suitable functional groups include, for example, amino, carboxyl, sulfhydryl, maleimide, isocyanate, isothiocyanate. Alternatively,
10 label moieties such as enzymes and chromogens may be conjugated to antibodies or nucleotides by means of coupling agents, such as dialdehydes, carbodiimides, dimaleimides, and the like. The label moiety may also be conjugated to the probe by means of a ligand attached to the probe by a method described above and a receptor for that ligand attached to the label moiety. Any of the known ligand-receptor binding
15 pair combinations is suitable. Some suitable ligand-receptor pairs include, for example, biotin-avidin or biotin-streptavidin, and antibody-antigen.

Methods of Using pal Polynucleotides and PAL Polypeptides

20 The scientific value of the information contributed through the disclosures of the DNA and amino acid sequences of the present invention is apparent to one skilled in the art. As one series of examples, knowledge of the sequence of a cDNA or a genomic DNA for PAL makes possible (*e.g.*, through use of Southern hybridization or polymerase chain reaction (PCR)) the identification of genomic DNA sequences encoding PAL and pal expression control regulatory sequences, and will aid in
25 mutagenesis to obtain variants which have enhanced enzyme properties. DNA/DNA hybridization procedures carried out with DNA sequences of the invention under moderately to highly stringent conditions are also expected to allow the isolation of DNAs encoding allelic variants of pal. Similarly, non-yeast species genes encoding proteins homologous to PAL can also be identified by Southern and/or PCR analysis.
30 As an alternative, complementation studies can be useful for identifying other yeast PAL products as well as non-yeast proteins, and DNAs encoding the proteins, sharing

one or more biological properties of PAL. Oligonucleotides of the invention are also useful in hybridization assays to detect the capacity of cells to express pal. Polynucleotides of the invention may also be the basis for diagnostic methods useful for identifying a genetic alteration in the pal locus that underlies a disease state.

5 Oligonucleotides and polynucleotides of the invention, as described herein, may be used in methods to amplify DNA for various purposes. "Amplification" according to the method of the invention refers to any molecular biology technique for detection of trace levels of a specific nucleic acid sequence by exponentially amplifying a template nucleic acid sequence. In particular, suitable amplification
10 techniques include such techniques as the polymerase chain reaction (PCR), the ligase chain reaction (LCR) and variants thereof. PCR is known to be a highly sensitive technique, and is in wide use. PCR is described, for example, in Innis et al., *PCR Protocols: A Guide to Methods and Applications*, Academic Press, Inc., San Diego (1990); Dieffenbach and Dveksler, *PCR Primer: A Laboratory Manual*, Cold Spring
15 Harbor Laboratory Press, Plainview NY (1995); and U.S. Patents Nos. 4,683,195, 4,800,195, and 4,965,188. LCR is more recently developed and is described in Landegren et al. (Science 241:1077 (1988)) and Barany et al. (PCR Methods and Applications 1:5 (1991)). An LCR kit is available from Stratagene. LCR is known to be highly specific, and is capable of detecting point mutations. In certain
20 circumstances, it is desirable to couple the PCR and LCR techniques to improve precision of detection. Other amplification techniques may be employed in accordance to the invention.

Oligonucleotide amplification primers are often provided as matched pairs of single-stranded oligonucleotides; one with sense orientation (5' → 3') and one with
25 antisense (3' ← 5') orientation. Such specific primer pairs can be employed under optimized conditions for identification of a specific gene or condition. Alternatively, the same primer pair, nested sets of oligomers, or even a degenerate pool of oligomers, may be employed under less stringent conditions for detection and/or quantitation of closely related DNA or RNA sequences.

30 Oligonucleotides and polynucleotides can be used in various methods known in the art to extend the specified nucleotide sequences. These methods permit use of a

known sequence to determine an unknown adjacent sequence, thereby enabling detection and determination of upstream sequences such as promoters and regulatory elements. Exemplary methods are described in Gobinda et al., *PCR Methods Applic.*, 2:318-322 (1993)); Triglia et al., *Nucleic Acids Res.*, 16:8186 (1988); Lagerstrom et al., *PCR Methods Applic.*, 1:111-119 (1991); Parker et al., *Nucleic Acids Res.*, 19:3055-3060 (1991). Commercial kits are also available, e.g., the PromoterFinder™ kit available from Clontech (Palo Alto CA).

For example, restriction-site polymerase chain reaction is a direct method that uses universal primers to retrieve unknown sequence adjacent to a known locus. See, e.g., Gobinda et al., *PCR Methods Applic.*, 2:318-22 (1993). In this method, genomic DNA is first amplified in the presence of primer to a linker sequence and a primer specific to the known region. The amplified sequences are subjected to a second round of PCR with the same linker primer and another specific primer internal to the first one. Products of each round of PCR are transcribed with an appropriate RNA polymerase and sequenced using reverse transcriptase.

Inverse PCR can be used to amplify or extend sequences using divergent primers based on a known region (Triglia et al., *Nucleic Acids Res.*, 16:8186 (1988)). The primers may be designed using Oligo 4.0 (National Biosciences, Inc., Plymouth MN), or another appropriate program, to be 22-30 nucleotides in length, to have a GC content of 50% or more, and to anneal to the target sequence at temperatures about 68°-72°C. This method uses several restriction enzymes to generate a suitable fragment in the known region of a gene. The fragment is then circularized by intramolecular ligation and used as a PCR template.

Capture PCR is a method for PCR amplification of DNA fragments adjacent to a known sequence in yeast and yeast artificial chromosome (YAC) DNA (Lagerstrom et al., *PCR Methods Applic.*, 1:111-119 (1991)). Capture PCR also requires multiple restriction enzyme digestions and ligations to place an engineered double-stranded sequence into an unknown portion of the DNA molecule before PCR. Parker et al., *Nucleic Acids Res.*, 19:3055-3060 (1991)), teach walking PCR, a method for targeted gene walking that permits retrieval of unknown sequence. PromoterFinder™ is a kit available from Clontech (Palo Alto, CA) that uses PCR,

nested primers, and special libraries to "walk in" genomic DNA. This process avoids the need to screen libraries and is useful in finding intron/exon junctions.

Such methods can be used to explore genomic libraries to extend 5' sequence and to obtain endogenous pal genomic sequence, including elements such as promoters, introns, operators, enhancers, repressors, and the like. Preferred libraries for screening for full-length cDNAs are ones that have been size-selected to include larger cDNAs. In addition, randomly primed libraries are preferred in that they will contain more sequences that contain the 5' and upstream regions of genes.

The oligonucleotide probes may also be used for mapping the endogenous genomic sequence. The sequence may be mapped to a particular chromosome or to a specific region of the chromosome using well known techniques. These include in situ hybridization to chromosomal spreads (Venna et al., *Yeast Chromosomes: A Manual of Basic Technique*, Pergamon Press, New York NY (1988)), flow-sorted chromosomal preparations, or artificial chromosome constructions such as YACs, bacterial artificial chromosomes (BACs), bacterial P1 constructions, or single chromosome cDNA libraries.

The DNA sequence information provided by the present invention also makes possible the development, e.g., through homologous recombination or "knock-out" strategies (Capecci, *Science*, 244:1288-1292 (1989)), of microbes that fail to express functional pal or that express a variant of pal. Such microbes are useful as models for studying the activities of PAL.

As described herein, the invention provides antisense nucleic acid sequences that recognize and hybridize to polynucleotides encoding PAL. Modifications of gene expression can be obtained by designing antisense sequences to the control regions of the pal gene, such as the promoters, enhancers, and introns. Oligonucleotides derived from the transcription initiation site, e.g., between -10 and +10 regions of the leader sequence, are preferred. Antisense RNA and DNA molecules may also be designed to block translation of mRNA by preventing the transcript from binding to ribosomes. The worker of ordinary skill will appreciate that antisense molecules of the invention include those that specifically recognize and hybridize to pal DNA (as determined by sequence comparison of pal DNA to DNA encoding other known molecules). The

antisense molecules of the invention also include those that recognize and hybridize to DNA encoding other members of the PAL family of proteins. Antisense polynucleotides that hybridize to multiple DNAs encoding other members of the PAL family of proteins are also identifiable through sequence comparison to identify characteristic or signature sequences for the family of PAL proteins. Accordingly, such antisense molecules preferably have at least 95%, more preferably at least 98%, and still more preferably at least 99% identity to the target pal sequence.

Antisense polynucleotides are particularly relevant to regulating expression of pal by those cells expressing pal mRNA. Antisense polynucleotides (preferably 10 to 20 bp oligonucleotides) capable of specifically binding to pal expression control sequences or pal RNA are introduced into cells, *e.g.*, by a viral vector or a colloidal dispersion system such as a liposome. The antisense oligonucleotide binds to the pal target nucleotide sequence in the cell and prevents transcription or translation of the target sequence. Phosphorothioate and methylphosphonate antisense oligonucleotides are specifically contemplated for therapeutic use under the invention. The antisense oligonucleotides may be further modified by poly-L-lysine, transferrin polylysine, or cholesterol moieties at their 5' ends. For a recent review of antisense technology, see Delihias et al., *Nature Biotechnology*, 15:751-753 (1997).

The invention further comprises methods to modulate pal expression by means of ribozyme technology. For a review, see Gibson and Shillitoe, *Mol. Biotechnol.*, 7:125-137 (1997). Ribozyme technology can be used to inhibit translation of pal mRNA in a sequence-specific manner through: (i) the hybridization of a complementary RNA to a target mRNA; and (ii) cleavage of the hybridized mRNA through endonuclease activity inherent to the complementary RNA. Ribozymes can be identified by empirical methods such as using complementary oligonucleotides in ribonuclease protection assays, but more preferably are specifically designed based on scanning the target molecule for accessible ribozyme cleavage sites (Bramlage et al., *Trends Biotechnol.*, 16:434-438 (1998)). Delivery of ribozymes to target cells can be accomplished using either exogenous or endogenous delivery techniques well known and practiced in the art. Exogenous methods can include use of targeting liposomes

or micro-injection. Endogenous methods include use of viral vectors and non-viral plasmids.

Ribozymes can specifically modulate expression of pal when designed to be complementary to regions unique to a polynucleotide encoding PAL. "Specifically modulate," therefore is intended to mean that ribozymes of the invention recognize only a polynucleotide encoding PAL. Similarly, ribozymes can be designed to modulate expression of all or some of the PAL family of proteins. Ribozymes of this type are designed to recognize nucleotide sequences conserved all or some of the polynucleotides encoding the PAL family members.

The invention further embraces methods to modulate transcription of pal through use of oligonucleotide-directed triple helix formation (also known as Hogeboom base-pairing methodology). For a review, see Lavrovsky et al., *Biochem. Mol. Med.*, 62:11- 22 (1997). Triple helix formation is accomplished using sequence-specific oligonucleotides that hybridize to double stranded DNA in the major groove as defined in the Watson-Crick model. This triple helix hybridization compromises the ability of the original double helix to open sufficiently for the binding of polymerases, transcription factors, or regulatory molecules. Preferred target sequences for hybridization include promoter and enhancer regions to permit transcriptional regulation of pal expression. Oligonucleotides that are capable of triple helix formation can alternatively be coupled to DNA damaging agents, which can then be used for site-specific covalent modification of target DNA sequences. See Lavrovsky et al. *supra*.

Both antisense RNA and DNA molecules and ribozymes of the invention can be prepared by any method known in the art for the synthesis of RNA molecules. These include techniques for chemically synthesizing oligonucleotides such as solid-phase phosphoramidite chemical synthesis. Alternatively, RNA molecules may be generated by *in vitro* or *in vivo* transcription of DNA sequences encoding the antisense RNA molecule. Such DNA sequences can be incorporated into a variety of vectors with suitable RNA polymerase promoters such as T7 or SP6. Alternatively, antisense cDNA constructs that synthesize antisense RNA constitutively or inducibly can be introduced into cell lines, cells, or tissues.

Mutations in a gene that result in loss of normal function of the gene product may exhibit a deleterious phenotype in yeast, and introduction of the gene in mammals may have a beneficial effect. The invention thus comprehends introduction of the gene (*i.e.*, "gene therapy") to either introduce or restore PAL activity as indicated in treating those disease states characterized by a deficiency or absence of phenylalanine ammonia lyase activity associated with the PAL enzyme. Delivery of functional PAL-encoding sequence to appropriate cells is effected *ex vivo*, *in situ*, or *in vivo* by use of vectors, and more particularly viral vectors (*e.g.*, adenovirus, adeno-associated virus, or retrovirus), or *ex vivo* by use of physical DNA transfer methods (*e.g.*, liposomes or chemical treatments). See, for example, Anderson, *Nature*, 392(6679 Suppl):25-30 (1998). Alternatively, it is contemplated that in other disease states, preventing the expression or inhibiting the activity of PAL will be useful in treating those disease states. Antisense therapy or gene therapy can be applied to negatively regulate the expression of pal polynucleotide sequences.

The DNA and amino acid sequence information provided by the present invention also makes possible the systematic analysis of the structure and function of PAL proteins. DNA and amino acid sequence information for PAL also permits identification of molecules with which a PAL polypeptide will interact. Agents that modulate (*i.e.*, increase, decrease, or block) PAL activity may be identified by incubating a putative modulator with PAL and determining the effect of the putative modulator on PAL activity. The selectivity of a compound that modulates the activity of the PAL polypeptide can be evaluated by comparing its activity on the PAL to its activity on other proteins.

Selective modulators may include, for example, antibodies and other proteins or peptides that specifically bind to a PAL polypeptide or a PAL-encoding polynucleotide, oligonucleotides or polynucleotides that specifically bind to PAL-encoding polynucleotides, and other non-peptide compounds (*e.g.*, isolated or synthetic organic molecules) that specifically react with PAL polypeptides or PAL-encoding polynucleotides. Mutant forms of pal, such as those that affect the biological activity or cellular location of the wild-type pal, are also contemplated according to the invention. Still other selective modulators include those that

recognize specific regulatory or PAL-encoding nucleotide sequences. Modulators of PAL activity may be therapeutically useful in treatment of a wide range of diseases and physiological conditions in which aberrant PAL activity is involved, or may be useful in the commercial production of phenylalanine, phenylalanine analogs, or other optically-active unnatural amino acids having phenylalanine-like structures.

Given the relationship of phenylalanine with phenylketonuria and potentially cancer, and the use of a phenylalanine-like architecture in the pharmacophores of protease inhibitors presently employed in treating human immunodeficiency virus and human cytomegalovirus infections, a PAL-encoding polynucleotide sequence may be used for the diagnosis of diseases resulting from, associated with, or ameliorated by pal expression or PAL activity *e.g.*, phenylketonuria, cancer, human immunodeficiency virus infection, and/or cytomegalovirus infection. Qualitative or quantitative methods may include Southern or Northern analysis, dot blot, or other membrane-based technologies; PCR technologies; dipstick, pin or chip technologies; and ELISA or other multiple-sample format technologies, which all can be carried out either in the presence or absence of exogenous pal polynucleotide or PAL polypeptide *e.g.*, phenylketonuria, cancer, human immunodeficiency virus infection, and/or cytomegalovirus infection. These types of techniques are well known in the art and have been employed in commercially available diagnostic kits.

Such assays may be tailored to evaluate the efficacy of a particular therapeutic treatment regimen and may be used in animal studies, in clinical trials, or in monitoring the treatment of an individual patient, or can be employed in microbial (*e.g.*, yeast studies). To provide a basis for the diagnosis of disease, a normal or standard profile for pal expression must be established. This is accomplished by combining a biological sample taken from a normal subject with a pal polynucleotide, under conditions suitable for hybridization or amplification. Standard hybridization may be quantified by comparing the values obtained for normal subjects with a dilution series of positive controls run in the same experiment where a known amount of a purified pal polynucleotide is used. Standard values obtained from normal samples may be compared with values obtained from samples from subjects (or yeast samples) potentially affected by a disorder or disease related to pal expression.

Deviation between standard and subject values establishes the presence of the disease state. If disease is established, an existing therapeutic agent is administered, if so desired, and treatment profile or values may be generated. The assay may be repeated on a regular basis to evaluate whether the values progress toward or return to the normal or standard pattern. Successive treatment profiles may be used to show the efficacy of treatment over a period of several days or several months.

In particular, anti-PAL antibodies may be useful for the diagnosis of conditions, disorders, or diseases characterized by or associated with abnormal expression of a PAL polypeptide, and/or to detect yeast aberrant or excessive PAL production. Assays (including diagnostic assays) for PAL polypeptides include methods that employ a labeled antibody to detect a PAL polypeptide in a biological sample such as a body fluid, cells, tissues, sections, or extracts of such materials. Preferably, the polypeptide or the antibody will be labeled by linking them, either covalently or non-covalently, with a detectable label moiety as described herein.

Antibody-based methods for detecting the presence of PAL polypeptides in biological samples are based on previously described assays for detecting the presence of proteins with antibodies, and follow known formats, such as enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), and X fluorescence-activated cell sorting (FACS) and flow cytometry, Western analysis, sandwich assays, and the like. These formats are normally based on incubating an antibody with a sample suspected of containing the PAL protein and detecting the presence of a complex between the antibody and the protein. The antibody is labeled either before, during, or after the incubation step. The specific concentrations of antibodies, the temperature and time of incubation, as well as other such assay conditions, can be varied, depending upon various factors including the concentration of antigen in the sample, the nature of the sample, etc. Those skilled in the art will be able to determine operative and optimal assay conditions for each determination by employing routine experimentation. See, e.g., Hampton et al., *Serological Methods: A Laboratory Manual*, APS Press, St Paul MN (1990).

To provide a basis for the quantitation of PAL protein in a sample or for the diagnosis of disease, normal or standard values of PAL polypeptide expression must

be established. This is accomplished by combining body fluids or cell extracts taken from a normal sample or from normal subjects, either animal or yeast, with antibody to a PAL polypeptide. The amount of standard complex formation may be quantified by comparing it with a dilution series of positive controls where a known amount of antibody is combined with known concentrations of a purified PAL polypeptide. Then, standard values obtained from normal samples may be compared with values obtained from samples from test sample, *e.g.*, subjects potentially affected by a disorder or disease related to pal expression. Deviation between standard and test values establishes the presence of the disease state.

The invention further provides a method for increasing the expression or activity of PAL (*i.e.*, including "increasing" in the sense of supplying this activity to a host that normally does not contain it) and/or for industrial uses. The method comprises administering a pal polynucleotide, a PAL polypeptide, and/or a PAL agonist in an amount effective for increasing pal expression or PAL activity. This method may be employed in yeast or mammals. As employed in mammals, the method may prove useful in the treatment of any condition whose symptoms or pathology is mediated by or ameliorated by pal expression or PAL activity (*e.g.*, for mammals, phenylketonuria and/or cancer prophylaxis/therapeutics). In terms of industrial uses (*e.g.*, in yeast or other appropriate production host), PAL produced by recombinant means can be used in the commercial production of phenylalanine, phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures. For instance, the enzyme can be employed instead of a fermentation culture for the production of phenylalanine, phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures, or can be added into a fermentation culture that already contains a PAL producing strain. Other possibilities and variations would be apparent to those skilled in the art.

"Treating" as used herein refers to preventing a disorder from occurring in a mammal (especially a human) that may be predisposed to the disorder, but has not yet been diagnosed as having it; inhibiting the disorder, *i.e.*, arresting its development; relieving the disorder, *i.e.*, causing its regression, or ameliorating the disorder, *i.e.*, reducing the severity of symptoms associated with the disorder. "Disorder" is

intended to encompass medical disorders, diseases, conditions, syndromes, and the like, without limitation.

In particular, the method of the invention may be employed to treat mammals (*i.e.*, especially humans) therapeutically or prophylactically, for instance, mammals that are or may be subject to phenylketonuria. The invention also relates to a method of treating neoplastic tissue growth, *e.g.*, cancer, in a mammal, comprising administering to the mammal an effective amount of PAL. In this embodiment, the method may further comprise adjuvant administration of a chemotherapeutic or anti-cancer drug and/or radiation therapy.

Tumors or neoplasms include new growths of tissue in which the multiplication of cells is uncontrolled and progressive. Some such growths are benign, but others are termed "malignant," leading to death of the organism. Malignant neoplasms or "cancers" are distinguished from benign growths in that, in addition to exhibiting aggressive cellular proliferation, cancers invade surrounding tissues and metastasize. Moreover, malignant neoplasms are characterized in that they show a greater loss of differentiation (greater "dedifferentiation"), and of their organization relative to one another and their surrounding tissues. This property is also called "anaplasia."

Expression vectors derived from retroviruses, adenovirus, herpes, or vaccinia viruses, or from various bacterial plasmids, may be used for delivery of recombinant pal sense or antisense molecules to the targeted cell population. Methods that are well known to those skilled in the art can be used to construct recombinant vectors containing pal. See, for example, the techniques described in Sambrook et al., *supra*, and Ausubel et al., *supra*. Alternatively, recombinant pal can be delivered to target cells in liposomes.

The full-length cDNA or genomic sequences, and/or regulatory elements obtained therefrom, enable researchers to use a pal polynucleotide as a tool in sense (Yousoufian and Lodish, *Mol. Cell. Biol.*, 13:98-104 (1993)) or antisense (Eguchi et al., *Annu. Rev. Biochem.*, 60:631- 652 (1991)) investigations of gene function. Oligonucleotides, designed from the cDNA or control sequences obtained from the genomic DNA, can be used *in vitro* or *in vivo* to inhibit expression. Such technology

is now well known in the art, and sense or antisense oligonucleotides or larger fragments can be designed from various locations along the coding or control regions.

Additionally, pal expression can be modulated by transfecting a cell or tissue with expression vectors that express high levels of a pal polynucleotide fragment in conditions where it would be preferably to block a biological activity of PAL. Such constructs can flood cells with untranslatable sense or antisense sequences. Even in the absence of integration into the DNA, such vectors may continue to transcribe RNA molecules until all copies of the vector are disabled by endogenous nucleases. Such transient expression may be accomplished using a non-replicating vector or a vector incorporating appropriate replication elements.

Methods for introducing vectors into cells or tissue include those methods discussed herein. In addition, several of these transformation or transfection methods are equally suitable for *ex vivo* therapy. Furthermore, the pal polynucleotide sequences disclosed herein may be used in molecular biology techniques that have not yet been developed, provided the new techniques rely on properties of nucleotide sequences that are currently known, including but not limited to such properties as the triplet genetic code and specific base pair interactions.

Preparation of Antibodies immunoreactive with PAL Polypeptides

The present invention allows for the production of antibodies with specificity for PAL polypeptide. Antibodies to PAL may be produced by any method known in the art typically including, for example, the immunization of laboratory animals with preparations of purified native PAL, purified recombinant PAL, purified recombinant peptide fragments of PAL, or synthetic peptides derived from the PAL predicted amino acid sequence. This is discussed in Harlow et al. (Eds.), *Antibodies: A Laboratory Manual*, Cold Spring Harbor Laboratory, Cold Spring Harbor NY (1988). Also, antibodies that have been described in the art and are known to react with PAL can be employed according to the invention.

PAL Compositions

The present invention thus further relates to PAL polypeptide-containing compositions including pharmaceutical compositions. Pharmaceutical compositions optionally comprise PAL polypeptide or pal polynucleotide, or comprise a chemical or biological compound ("agent") that is active as a modulator of pal expression or PAL activity, along with a biocompatible pharmaceutical carrier, adjuvant, or vehicle. The active agent in the compositions (e.g., pharmaceutical compositions) accordingly may be selected from among all or portions of pal polynucleotide sequences, pal antisense molecules, PAL polypeptides, protein, peptide, or organic modulators of PAL bioactivity, such as inhibitors, antagonists (including antibodies) or agonists. Preferably, the agent is active in treating a medical condition that is mediated by, characterized by, or ameliorated by, pal expression or PAL activity. The composition can include the agent as the only active moiety or in combination with other nucleotide sequences, polypeptides, drugs, or hormones mixed with excipient(s) or other pharmaceutically acceptable carriers. Compositions other than pharmaceutical compositions optionally comprise liquid, i.e., water or a water-based liquid. Desirably, such a composition employed for industrial fermentation optimally contains components necessary for such fermentation, e.g., culture media, plus any stabilizers, additives, antibodies, host cells, or others. A composition employed for industrial fermentation further optionally can comprise added PAL polypeptide.

Pharmaceutically acceptable excipients to be added to pharmaceutical compositions also are well-known to those who are skilled in the art, and are readily available. The choice of excipient will be determined in part by the particular method used to administer the product according to the invention. Accordingly, there is a wide variety of suitable formulations for use in the context of the present invention.

The following methods and excipients are merely exemplary and are in no way limiting.

Techniques for formulation and administration of pharmaceutical compositions may be found in *Remington's Pharmaceutical Sciences*, 18th Ed., Mack Publishing Co, Easton PA, 1990, and are well known to those skilled in the art. The choice of excipient will be determined in part by the particular method used to administer the product according to the invention. Accordingly, there is a wide variety

of suitable formulations for use in the context of the present invention. The following methods and excipients are merely exemplary and are in no way limiting.

The pharmaceutical compositions of the present invention may be manufactured using any conventional method, *e.g.*, mixing, dissolving, granulating, dragée-making, levigating, emulsifying, encapsulating, entrapping, melt-spinning, spray-drying, or lyophilizing processes. However, the optimal pharmaceutical formulation will be determined by one of skill in the art depending on the route of administration and the desired dosage. Such formulations may influence the physical state, stability, rate of *in vivo* release, and rate of *in vivo* clearance of the administered agent. Depending on the condition being treated, these pharmaceutical compositions may be formulated and administered systemically or locally.

The pharmaceutical compositions may be administered to the subject by any conventional method, including parenteral and enteral techniques. Parenteral administration modalities include those in which the composition is administered by a route other than through the gastrointestinal tract, for example, intravenous, intraarterial, intraperitoneal, intramedullary, intramuscular, intraarticular, intrathecal, and intraventricular injections. Enteral administration modalities include, for example, oral (including buccal and sublingual) and rectal administration. Transepithelial administration modalities include, for example, transmucosal administration and transdermal administration. Transmucosal administration includes, for example, enteral administration as well as nasal, inhalation, and deep lung administration; vaginal administration; and rectal administration. Transdermal administration includes passive or active transdermal or transcutaneous modalities, including, for example, patches and iontophoresis devices, as well as topical application of pastes, salves, or ointments. Surgical techniques include implantation of depot (reservoir) compositions, osmotic pumps, and the like. A preferred route of administration for treatment of inflammation would be local or topical delivery for localized inflammation such as arthritis, and intravenous delivery for reperfusion injury or for systemic conditions such as septicemia.

The pharmaceutical compositions are formulated to contain suitable pharmaceutically acceptable carriers, and may optionally comprise excipients and

auxiliaries that facilitate processing of the active compounds into preparations that can be used pharmaceutically. The administration modality will generally determine the nature of the carrier. For example, formulations for parenteral administration may comprise aqueous solutions of the active compounds in water-soluble form. Carriers
5 suitable for parenteral administration can be selected from among saline, buffered saline, dextrose, water, and other physiologically compatible solutions. Preferred carriers for parenteral administration are physiologically compatible buffers such as Hank's solution, Ringer's solutions, or physiologically buffered saline. For tissue or cellular administration, penetrants appropriate to the particular barrier to be permeated
10 are used in the formulation. Such penetrants are generally known in the art. For preparations comprising proteins, the formulation may include stabilizing materials, such as polyols (*e.g.*, sucrose) and/or surfactants (*e.g.*, nonionic surfactants), and the like.

Alternatively, formulations for parenteral use may comprise suspensions of the
15 active compounds prepared as appropriate oily injection suspensions. Suitable lipophilic solvents or vehicles include fatty oils, such as sesame oil, and synthetic fatty acid esters, such as ethyl oleate or triglycerides, or liposomes. Aqueous injection suspensions may contain substances that increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol, or dextran. Optionally, the suspension
20 may also contain suitable stabilizers or agents that increase the solubility of the compounds to allow for the preparation of highly concentrated solutions. Emulsions, *e.g.*, oil-in-water and water-in-oil dispersions, can also be used, optionally stabilized by an emulsifying agent or dispersant (surface-active materials; surfactants). Liposomes containing the active agent may also be employed for parenteral
25 administration.

Alternatively, the pharmaceutical compositions comprising the agent in dosages suitable for oral administration can be formulated using pharmaceutically acceptable carriers well known in the art. The preparations formulated for oral administration may be in the form of tablets, pills, capsules, cachets, dragées,
30 lozenges, liquids, gels, syrups, slurries, suspensions, or powders. To illustrate, pharmaceutical preparations for oral use can be obtained by combining the active

compounds with a solid excipient, optionally grinding the resulting mixture, and processing the mixture of granules, after adding suitable auxiliaries if desired, to obtain tablets or dragée cores. Note that oral formulations may employ liquid carriers similar in type to those described for parenteral use, *e.g.*, buffered aqueous solutions, suspensions, and the like.

Preferred oral formulations include tablets, dragées, and gelatin capsules. These preparations may contain one or excipients, which include, without limitation:

- a) diluents such as sugars, including lactose, dextrose, sucrose, mannitol, or sorbitol;
- b) binders such as magnesium aluminum silicate, starch from corn, wheat, rice, potato, etc.;
- c) cellulose materials such as methyl cellulose, hydroxypropylmethyl cellulose, and sodium carboxymethyl cellulose, polyvinyl pyrrolidone, gums such as gum arabic and gum tragacanth, and proteins such as gelatin and collagen;
- d) disintegrating or solubilizing agents such as cross-linked polyvinyl pyrrolidone, starches, agar, alginic acid or a salt thereof such as sodium alginate, or effervescent compositions;
- e) lubricants such as silica, talc, stearic acid or its magnesium or calcium salt, and polyethylene glycol;
- f) flavorants, and sweeteners;
- g) colorants or pigments, *e.g.*, to identify the product or to characterize the quantity (dosage) of active compound; and
- h) other ingredients such as preservatives, stabilizers, swelling agents, emulsifying agents, solution promoters, salts for regulating osmotic pressure, and buffers.

Gelatin capsules include push-fit capsules made of gelatin, as well as soft, sealed capsules made of gelatin and a coating such as glycerol or sorbitol. Push-fit capsules can contain the active ingredient(s) mixed with fillers, binders, lubricants, and/or stabilizers, etc. In soft capsules, the active compounds may be dissolved or suspended in suitable fluids, such as fatty oils, liquid paraffin, or liquid polyethylene glycol with or without stabilizers.

Dragée cores can be provided with suitable coatings such as concentrated sugar solutions, which may also contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures.

- 5 The pharmaceutical composition may be provided as a salt of the active agent, which can be formed with many acids, including but not limited to hydrochloric, sulfuric, acetic, lactic, tartaric, malic, succinic, etc. Salts tend to be more soluble in aqueous or other protonic solvents that are the corresponding free base forms.

- 10 As noted above, the characteristics of the agent itself and the formulation of the agent can influence the physical state, stability, rate of *in vivo* release, and rate of *in vivo* clearance of the administered agent. Such pharmacokinetic and pharmacodynamic information can be collected through pre-clinical *in vitro* and *in vivo* studies, later confirmed in humans during the course of clinical trials. Thus, for any compound used in the method of the invention, a therapeutically effective dose in
15 mammals, particularly humans, can be estimated initially from biochemical and/or cell-based assays. Then, dosage can be formulated in animal models to achieve a desirable circulating concentration range that modulates pal expression or PAL activity. As human studies are conducted, further information will emerge regarding the appropriate dosage levels and duration of treatment for various diseases and
20 conditions.

- Toxicity and therapeutic efficacy of such compounds can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, *e.g.*, for determining the LD₅₀ (the dose lethal to 50% of the population) and the ED₅₀ (the dose therapeutically effective in 50% of the population). The dose ratio between toxic
25 and therapeutic effects is the "therapeutic index," which is typically expressed as the ratio LD₅₀/ED₅₀. Compounds that exhibit large therapeutic indices are preferred. The data obtained from such cell culture assays and additional animal studies can be used in formulating a range of dosage for human use. The dosage of such compounds lies preferably within a range of circulating concentrations that include the ED₅₀ with little
30 or no toxicity. Of course, similar studies can be conducted to ensure addition of PAL in either its polypeptide or polynucleotide-encoding form to microbial fermentation

cultures can be carried out, *e.g.*, to ensure optimal manufacture of L-phenylalanine (for instance, from ammonia and *t*-cinnamate), or production of phenylalanine analogs, and other optically active unnatural amino acids having phenylalanine-like structures.

5 For the method of the invention, any effective administration regimen regulating the timing and sequence of doses may be used. Doses of the agent preferably include pharmaceutical dosage units comprising an effective amount of the agent. As used herein, "effective amount" refers to an amount sufficient to provide or modulate pal expression or PAL activity and/or to derive a measurable change in a
10 physiological parameter of the host cell or subject through administration of one or more of the pharmaceutical dosage units.

Exemplary dosage levels for a human subject are of the order of from about 0.001 milligram of active agent per kilogram body weight (mg/kg) to about 100 mg/kg. Typically, dosage units of the active agent comprise from about 0.01 mg to
15 about 10,000 mg, preferably from about 0.1 mg to about 1,000 mg, depending upon the indication, route of administration, etc. Depending on the route of administration, a suitable dose may be calculated according to body weight, body surface area, or organ size. The final dosage regimen will be determined by the attending physician in view of good medical practice, considering various factors that modify the action of
20 drugs, *e.g.*, the agent's specific activity, the severity of the disease state, the responsiveness of the patient, the age, condition, body weight, sex, and diet of the patient, the severity of any infection, and the like. Additional factors that may be taken into account include time and frequency of administration, drug combination(s), reaction sensitivities, and tolerance/response to therapy. Further refinement of the
25 dosage appropriate for treatment involving any of the formulations mentioned herein is done routinely by the skilled practitioner without undue experimentation, especially in light of the dosage information and assays disclosed, as well as the pharmacokinetic data observed in yeast clinical trials. Appropriate dosages may be ascertained through use of established assays for determining concentration of the
30 agent in a body fluid or other sample together with dose response data.

5 The frequency of dosing will depend on the pharmacokinetic parameters of the agent and the route of administration. Dosage and administration are adjusted to provide sufficient levels of the active moiety or to maintain the desired effect. Accordingly, the pharmaceutical compositions can be administered in a single dose, multiple discrete doses, continuous infusion, sustained release depots, or combinations thereof, as required to maintain desired minimum level of the agent. Short-acting pharmaceutical compositions (*i.e.*, short half-life) can be administered once a day or more than once a day (*e.g.*, two, three, or four times a day). Long acting pharmaceutical compositions might be administered every 3 to 4 days, every week, or once every two weeks. Pumps, such as subcutaneous, intraperitoneal, or subdural pumps, may be preferred for continuous infusion.

15 Compositions comprising a compound of the invention formulated in a pharmaceutical acceptable carrier may be prepared, placed in an appropriate container, and labeled for treatment of an indicated condition. Conditions indicated on the label may include, but are not limited to, treatment and diagnosis of phenylketonuria. Kits are also contemplated, wherein the kit comprises a dosage form of a pharmaceutical composition and a package insert containing instructions for use of the composition in treatment of a medical condition.

20 **Examples**

The following examples further illustrate the present invention but, of course, should not be construed as in any way limiting its scope.

25 The examples presuppose an understanding of conventional methods well-known to those persons having ordinary skill in the art to which the examples pertain, *e.g.*, the construction of vectors and plasmids, the insertion of genes encoding polypeptides into such vectors and plasmids, or the introduction of vectors and plasmids into host cells. Such methods are described in detail in numerous publications including, for example, Sambrook et al., *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory Press (1989), Ausubel et al. 30 (*Eds.*), *Current Protocols in Molecular Biology*, John Wiley & Sons, Inc. (1994); and

Ausubel et al. (Eds.), *Short Protocols in Molecular Biology*, 4th ed., John Wiley & Sons, Inc. (1999).

Example 1: Obtaining a polynucleotide that encodes

5 ***Rhodotorula graminis* phenylalanine ammonia lyase**

This example describes the isolation and sequencing of a phenylalanine ammonia lyase cDNA.

The mutant strain of the yeast *Rhodotorula graminis*, strain (ATCC 20804), has been shown to produce 4-to-5 fold higher levels of inducible phenylalanine ammonia lyase (PAL) (Omdorff et al., 1988; U.S. Patent 4,757,015).

Cells of *R. graminis* strain ATCC 20804 were obtained from American Type Culture Collection (10801 University Boulevard, Manassas, VA 20110-2209), and maintained in 20% glycerol in liquid nitrogen. About 3 mls of cells from cryostorage were used to inoculate a Fernbach flask containing 1 L of PAL Fernbach Medium.

15 Cells were grown at 28°C for 30 hours with shaking at about 250 rpm. This initial culture was used to inoculate 12 L of PAL Fermentation Medium, which was incubated at 28°C (pH 6, 1 vvm air flow) with shaking at about 250 rpm for up to about 30 hours, with some aliquots removed at earlier times.

PAL Fernbach Medium comprises 10 g/L Amberex 695 yeast extract (*e.g.*, Red Star Bioproducts, Juneau, WI), 52.5 ml/L HFCS High Fructose Corn Syrup, and 0.1 ml/L Mazur antifoam agent (*e.g.*, made by PPG Industries Inc., Gurnee, IL). The pH of this medium was adjusted to 6.1 (*e.g.*, with 45% KOH). PAL Fermentation Medium comprises 5 g/L Amberex 695 yeast extract, 2.0 g/L ammonium phosphate, 9.0 g/L L-phenylalanine, and 1.5 g/L L-isoleucine, 0.4 ml Mazur antifoam agent.

25 The PAL gene was cloned using RT-PCR (reverse transcriptase-polymerase chain reaction). In a first step, total RNA was isolated from exponentially growing cells of ATCC 20804 using the RNeasy kit from Qiagen Inc. (Valencia, CA), according to manufacturer's instructions. A cDNA preparation was made from the RNA with the GIBCO BRL (Rockville, MD, now Invitrogen, Carlsbad, CA)

30 Superscript Preamplification kit. The cDNA was then amplified with touchdown PCR using degenerate primers (OLI 61, set forth as SEQ ID NO:1, and OLI 63, set forth as

SEQ ID NO:2) designed from the *R. rubra* PAL amino acid sequence and the codon usage patterns of the *R. graminis* mandelate dehydrogenase genes.

Touchdown PCR parameters were as follows. There was one cycle at 94°C, 4 minutes. This was followed by 2 cycles each, decreasing by one degree with each two
5 rounds of amplification as noted: 94°C, 30 seconds; 63°C-51°C, 20 seconds; 72°C, 2.5 minutes. This was followed by 25 cycles each: 94°C, 30 seconds; 50°C, 20 seconds; 72°C, 2.5 minutes. The final cycle was at 72°C, 10 minutes.

A PCR fragment of the desired size (approximately 2.1 kilobases, the size corresponding to the PAL coding sequence of *R. rubra*) was isolated and cloned into
10 the vector pBR322 and submitted for double stranded sequencing to Lark Technologies Inc. (Houston, TX).

The sequences of the specific ends of the *R. graminis* PAL gene were obtained using the DNA sequence determined above. Namely, the 5' end of the PAL gene was cloned, using the cDNA prepared above, with the GIBCO BRL (now Invitrogen,
15 Carlsbad, CA) 5' RACE kit. The 3' end of the cDNA was tailed with dC nucleotides and then amplified with a forward primer AAP (set forth as SEQ ID NO:3), which hybridizes to the polyC tail, and a gene-specific reverse primer GSP2 (set forth as SEQ ID NO:4) designed from the *R. graminis* PAL DNA sequence. After another round of amplification with nested primers AUAP (set forth as SEQ ID NO:5) and
20 GSP4 (set forth as SEQ ID NO:6), the fragment was cloned into the pCMV Sport-βgal vector and submitted to Lark Technologies, Inc. for sequencing. More specifically, for 5' RACE amplifications, for the amplification, there was 1 cycle at 94°C, 2 minutes. This was followed by 30 cycles: 94°C, 30 seconds; 57°C, 20 seconds; 72°C, 70 seconds. This was followed by one cycle at 72°C, 5 minutes.

25 The 3' end of the PAL gene was cloned using the 3' RACE kit from GIBCO BRL (now Invitrogen, Carlsbad, CA). First strand synthesis was performed using total RNA isolated from ATCC 20804 cells for the RT-PCR experiments. An oligo dT primer was employed that contains an adapter sequence AP (set forth as SEQ ID NO:7). The 3' end was amplified with a forward gene-specific primer (GSP5) (set
30 forth as SEQ ID NO:8) and a reverse primer (AUAP) (set forth as SEQ ID NO:5). After another round of amplification using primers AUAP and GSP6 (set forth as

SEQ ID NO:9), the fragment was cloned into pCMV Sport-β gal and submitted to Lark Technologies for sequencing. For 3' RACE amplifications, the same parameters were used as for the 5' RACE amplification.

5 **Example 2: Comparing the *Rhodotorula graminis* phenylalanine ammonia lyase polypeptide and polynucleotide sequence with those of other strains**

Other strains also can be employed in accordance with the invention to isolate PAL sequences. For instance, *R. graminis* strain KGX39 can be employed. This example accordingly describes the sequencing of the PAL cDNA of the parental *R.*
10 *graminis* strain, KGX39.

The PAL gene of KGX39 was isolated in a manner similar to ATCC 20804, but rather than using the degenerate primers described in Example 1, specific primers (*i.e.*, OLI 77 (set forth as SEQ ID NO:10) and OLI 78 (set forth as SEQ ID NO:11)) which correspond to sequences before and after the coding region of the ATCC 20804
15 PAL gene, were used to amplify PAL. The PAL fragment was cloned into the vector pBR322 and submitted to Lark Technologies for double-stranded sequencing. KGX39 PAL also was cloned using primers OLI 74 (set forth as SEQ ID NO:22) and OLI 75 (set forth as SEQ ID NO:23) which amplified just the coding region. These clones also were sequenced.

20 Based on the sequence information generated, the sequence of the coding region of KGX39 appears to be identical to that of ATCC 20804 with the possible exception of a single base change. Namely, as reflected in the sequences at SEQ ID NOS:12 and 13, the sequence obtained for ATCC 20804 contains a GTC at codon 153 (SEQ ID NO: 12 numbering), coding for Val, whereas the sequence obtained for
25 KGX39 contains GCC, coding for Ala. In view of the sequence obtained for genomic clones, it appears more likely that residue 153 is Val, coded for by GTC. This suggests that any difference in PAL activity between ATCC 20804 and its parent may be due to a mutation in the genomic coding sequence (*e.g.*, a regulatory mutation), or a difference in the polypeptides that interact with PAL.

30

Example 3: Comparing the *Rhodotorula graminis* phenylalanine ammonia lyase polypeptide and polynucleotide sequence with those of other species

Using the nucleotide sequence of ATCC 20804 PAL (set forth as SEQ ID NO:12) determined as described above, a search of sequences of other species was performed. For certain of these comparisons, the search was done using the polypeptide sequence anticipated (set forth as SEQ ID NO:13) based on translation of the polynucleotide sequence.

Initially, the search for similar sequences was conducted with BLASTP (default parameters) using the *R. rubra* sequence, before the *R. graminis* sequence was known. The 28 sequences obtained showing the best homology were then analyzed using the PILEUP Multiple Sequence Alignment program (with Gap Weight:12; Gap Length Weight: 4). After the *R. graminis* sequence was determined, it was added to the analysis.

Of these sequences uncovered, all 29 show homology in what is believed to be the active site. A visual inspection revealed strong and substantial differences between the sequences as compared to the PAL polypeptide (e.g., compare, for instance, the *Muscaria amanita* polynucleotide and polypeptide sequences at SEQ ID NOS:14 and 15, respectively), except for the yeast sequences Gil29592spp1024poly_Rhorb (*Rhodotorula rubra* PAL species) and Gil29593spp 11544paly_Rhoto (*Rhodospiridium toruloides* species), which appeared to have at least some similarity to the *R. graminis* PAL polypeptide.

The Clustal W program was then used to compare the *R. graminis* PAL polynucleotide and polypeptide sequence against the corresponding sequences in *R. toruloides* (i.e., GenBank Accession Number X51513) and *R. mucilaginosa* (i.e., GenBank Accession Number X13094 which formerly referred to *R. rubra* was updated as Accession Number X13095 to correspond to the re-classification of the strain as *Rhodotorula mucilaginosa*, and then was replaced by modified Accession Number X13094). In making these comparisons, only the exons of the sequences were included. The *R. toruloides* PAL counterpart sequences are set forth as SEQ ID NO:18 (polynucleotide) and SEQ ID NO:19 (polypeptide). The *R.*

rubra/mucilaginosa PAL counterpart sequences are set forth as SEQ ID NO:16 (polynucleotide) and SEQ ID NO:17 (polypeptide).

A comparison of these sequences with those of *R. graminis* is depicted in **Figures 1A-1B** (polypeptide sequence) and in **Figures 2A-2F** (polynucleotide sequence). The sequences displayed 62.9% identity, and 90.2% similarity at the amino acid level (**Figures 1A-1B**). The sequences displayed 56% identity, and 86% similarity at the nucleic acid level (**Figures 2A-2F**). The overall consensus between the sequences are set out in the Figures, as well as in SEQ ID NO:20 (polynucleotide sequence) and SEQ ID NO:21 (polypeptide sequence).

Example 4: Isolation of the *Rhodotorula graminis* phenylalanine ammonia lyase polypeptide

For these studies, the yeast strain *Rhodotorula graminis*, ATCC 20804 was grown in a 20-liter BiolaFitte fermentor using glucose-fed batch fermentation. The pH was maintained at 6.0 with use of 25% (v/v) H₂SO₄ or 10 N NaOH. The temperature was held at 28°C for 18 hours, followed by rapid cooling to less than 10°C. The cells were removed and concentrated via ultrafiltration, and stored generally as frozen beads, prepared by dripping into liquid nitrogen. These growth and storage conditions allowed for maximum PAL activity.

The inoculum was prepared as described in Example 1. Fermentation was carried out by maintaining the culture under cell growth conditions (agitation is 500 rpm, and the air flow is 1 vvm (12 slpm) at 28°C). When the initial glucose level falls to less than 1 g/L, then glucose is added back to 12g/L (268g). When the glucose level again drops to less than 1 g/L, 500 ml of 25% Amberex 695 and isoleucine feed (1.0 g/L concentrations in fermentor) are added. After peak PAL activity is determined, the tank is sparged and the headspace is overlaid with nitrogen. The sparge is shut off once the tank is anaerobic, the rpm is lowered to 250, and the tank is cooled to less than 20°C. When the fermentor is less than 20°C, the cells are harvested via ultrafiltration.

PAL activity of ATCC 20804 was determined by adding 20 µl of PAL cells (6-15 mg/ml), 50 mM Tris buffer, pH 8.8) to 980 µl of a solution containing 50 mM

Tris buffer (pH 8.8), 25 mM L-phenylalanine, and 0.001% (w/v) of cetylpyridinium chloride. The mixture was incubated at 30°C in a spectrophotometer, and the appearance of cinnamate was followed at 280 nm (or the corresponding λ_{max} for other substrates tested). The rate of increase in optical density was measured during a
5 period of linear increase. The ratio of the change in optical density at 280 nm per minute to the optical density (660 nm) of the cells in the reaction mixture, was used as a means to determine “specific activity” of the PAL strain ($\Delta\lambda_{\text{max}}/\text{min}/(\text{optical density, or “od”, 660 nm})$). Activities of purified PAL fractions were determined by adding 50 μl of each fraction to 150 μl assay solution to each well in a 96-well
10 microtiter plate. The plate was incubated at 30°C, and ΔA_{280} monitored with mixing between readings.

For enzyme purification, washed whole *R. graminis* cells were suspended in a 5X volume of 50 mM potassium phosphate buffer, pH 7.0, containing 25% (v/v) glycerol. The cells were disrupted using an M-110EH microfluidizer (Microfluidics,
15 Newton, MA) at 25,000 psi. The crude lysate was centrifuged to remove cell debris and obtain the PAL-containing cell extract. The extract was brought to a 30% ammonium sulfate saturation, and the precipitate was removed by centrifugation. The supernatant was then brought to a 65% ammonium sulfate saturation, and the enzyme-containing precipitate was removed by centrifugation. The pellet was resuspended in
20 50 mM Tris buffer (pH 8.5) containing about 25% (v/v) glycerol (buffer A). This was designated the ammonium sulfate (“AS”) fraction. The AS fraction was loaded onto an XK50 column (Pharmacia, Peapack, New Jersey) packed with 150 ml phenyl Sepharose HP (Pharmacia, Peapack, New Jersey) equilibrated in 50 mM potassium phosphate buffer (pH 7.0) containing 1.7 ammonium sulfate and 10% (v/v) glycerol
25 (buffer A). The column was eluted using a reverse linear gradient from 1.7 - 0 M ammonium sulfate (buffer B). The enzyme eluted at an ammonium sulfate concentration of approximately 170 mM, so the gradient was adjusted to 0.34 to 0 M ammonium sulfate, with the initial equilibration at 80% buffer B. The active fractions were pooled and designated the HIC fraction. The HIC fraction was brought to an
30 85% ammonium sulfate concentration, and the precipitated protein containing 95% of the activity was stored as a frozen pellet. The pellet was resuspended in a 25 mM

potassium phosphate buffer pH 7.0 containing 10% (v/v) glycerol, and dialyzed against 50 mM potassium phosphate, pH 7.0. Next, the concentrated/dialyzed HIC fraction was run on a AX1000 weak anion exchange column, 250 x 21.4 mm (SynChrom, Linden IN), using a 0.05 - 0.5M potassium phosphate (pH 7.0) gradient containing 10% (v/v) glycerol. The active fractions eluted at a conductivity of approximately 25 mS/cm, and were pooled and designated the AX fraction. The AX fraction was brought to an 85% ammonium sulfate concentration, and the precipitated protein containing 95% of the activity was stored as a frozen pellet. The enzyme was judged to be approximately 75% pure by SDS-PAGE analysis.

Protein was determined by the method of Bradford assay, using bovine serum albumin as a standard.

Example 5: Construction of pY141

This example describes the construction of plasmid pY141, which comprises the polynucleotide sequence of SEQ ID NO:12, and which encodes the sequence of SEQ ID NO:13. The PAL fragment was amplified from the cloned PAL described in Example 1 using primers OLI 105 (set forth as SEQ ID NO:24) and OLI 80 (set forth as SEQ ID NO:25) and the Clontech Advantage-HF PCR kit (Clontech Laboratories, Inc., Palo Alto, CA) according to manufacturer's directions. Touchdown PCR parameters were used as follows: One cycle each, decreasing by one degree with each round of amplification as noted: 94°C, 30 seconds; 70 - 62°C, 20 seconds; 72°C, 1 minute. This was followed by 20 cycles each: 94°C, 30 seconds; 61°C, 20 seconds; 72°C, 1 minute. The final cycle was at 72°C, 5 minutes. A PCR fragment of the desired size (approximately 2.1 kilobases) was isolated and ligated to the large EcoRI/SphI fragment of vector pBR322, resulting in plasmid pY141.

Plasmid pY141 was introduced into the host cell *E. coli* XL1-Blue, and the resultant strain RY624 was deposited with ATCC (American Type Culture Collection), 10801 University Boulevard, Manassas, VA 20110-2209, on July 12, 2000 as strain PTA-2224.

Example 6: pal Gene Sequence

This example described the isolation and sequencing of *R. graminis* phenylalanine ammonia lyase genomic DNA. The pal gene was isolated from wild-type strain KGX 39 and mutant strain ATCC 20804.

The genomic clones were prepared by amplification of the appropriate
5 chromosomal DNA with oligonucleotides OLI 89 (SEQ ID NO:26) and OLI 90 (SEQ ID NO:27). Chromosomal DNA was prepared using the Qiagen Genomic DNA Buffer Kit, following the manufacturer's protocol for yeast DNA isolation. For the genomic KGX39 PAL clone, the Clontech Advantage HF PCR kit was used with the following touchdown PCR parameters. There was one cycle at 95°C, 1 minute. This
10 was followed by 1 cycle each, decreasing by one degree with each round of amplification as noted: 94°C, 30 seconds; 68°C – 61°C, 20 seconds; 72°C, 1 minute. This was followed by 20 cycles: 94°C, 30 seconds; 60°C, 20 seconds; 72°C, 1 minute. The final cycle was 72°C, 5 minutes. The PCR fragment was isolated and cloned into a pBR322-based vector (*i.e.*, for convenience, pPOT5 constructed at NSC
15 Technologies, Mount Prospect, IL, although any pBR322-based vector conceivably could be employed). The PCR fragment was submitted for double stranded sequencing to ACGT, Inc. (Northbrook, IL).

For the genomic ATCC 20804 PAL clone, the Stratagene Pfu DNA polymerase kit was used with the following PCR parameters. There was one cycle at
20 95°C, 1 minute. This was followed by 25 cycles: 94°C, 35 seconds; 68°C, 35 seconds, 75°C, 4 minutes. The final cycle was 72°C, 5 minutes. The PCR fragment was isolated and cloned into a pBR322-based vector (pPOT5) and sequenced by ACGT, Inc. (Northbrook, IL).

25 **Example 7: Sequence of the *Rhodotorula graminis* Phenylalanine Ammonia Lyase Gene**

This example describes the *R. graminis* PAL genomic sequence.

Based on the sequence information generated (set forth as SEQ ID NO:28), the PAL gene isolated for both KGX39 (**Figure 4**) and ATCC 20804 (**Figure 3**)
30 appears to be identical except that the sequence obtained for ATCC 20804 contains a GCC at codon 2 (SEQ ID NO:12 numbering), coding for Ala, whereas the sequence obtained for KGX39 contains GCA, which also codes for Ala. This discrepancy

between the genomic sequences obtained, and the discrepancy in the cDNA sequences obtained (already discussed) creates a lack of identity in the cDNA and genomic sequences at codons 2 and 153. A further difference between the cDNA and genomic sequences is observed at nucleotide 2688 in SEQ ID NO:28, *i.e.*, a T, whereas the
5 corresponding position in SEQ ID NO:12, nucleotide 2298, is a C. This difference in noncoding DNA, like the other aforementioned differences, could be the result of a sequencing error. More important, as compared with the cDNA sequences, the coding region of the genomic sequences (as described in SEQ ID NO:28) is interrupted by the presence of introns at residues 362 to 448, 881 to 960, 1296 to 1364, 1530 to
10 1586, 1749 to 1821, and 1948 to 2007 (SEQ ID NO:28 numbering).

All of the references cited herein, and particularly U.S. Serial Number 09/624,693 filed July 24, 2000, and PCT International Application PCT/US01/23270
15 filed July 24, 2001, are hereby incorporated in their entireties by reference for all that they disclose.

While this invention has been described with an emphasis upon certain preferred embodiments, it will be obvious to those of ordinary skill in the art that variations in the preferred embodiments may be used, and that it is intended that the
20 invention may be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications encompassed within the spirit and scope of the invention as defined by the following claims.